EFFECTS OF CULTIVATION TECHNIQUES ON MAIZE PRODUCTIVITY AND SOIL PROPERTIES ON HILLSLOPES IN YUNNAN PROVINCE, CHINA

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Effects of Cultivation Techniques on Maize Productivity and Soil Properties on Hillslopes in Yunnan Province, China

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ABSTRACT

The rapid population increase in China from 556.7 to 1226.7 million during the past 50 years means China has one-sixth of the world's population. This population growth has imposed high pressures on Chinese agriculture. Crop production and productivities have more than doubled, for example mean maize yields have increased from 1.54 to 3.91 t ha^{-1} from 1960 to 1998. Despite this, food shortages remain major problems. These pressures have also led to intensive cultivation of sloping lands, making China the country with the most serious soil erosion problems in the world. Yunnan Province, south-west China, has some 70% of its total of 6.53 million hectares of cultivated fields located on sloping land, most of which suffers from soil erosion. Furthermore, traditional downslope cultivation of these upland fields produces increased soil loss and runoff and threatens agricultural sustainability. Crop yields on sloping land in these areas have decreased by 30-60% in the last century because of soil erosion and in 50-100 years most topsoil may have been removed. There is an urgent need to develop more productive and sustainable cropping systems and the dual aims of this project were to investigate ways of increasing productivity of maize on sloping land, while conserving soils.

This investigation was carried out in Wang Jia Catchment (25^{0}28'N,102^{0}53'E), selected as a representative area of fragile slopes in Yunnan Province. Five treatments (1) Traditional + Downslope planting (control), (2) Traditional + Contour planting, (3) Traditional + Contour + Straw mulch, (4) Minimum tillage + Contour + Straw mulch and (5) Traditional + Contour + Polythene mulch, were selected for evaluation and established on replicated field plots in 1998 and 1999. An additional experiment in 1999 investigated the effects of irrigation on crop yield.

Although there were variations during the growing season and between years, straw mulch with contour planting increased soil moisture (0-20 cm depth) and was associated with lower soil temperatures. Polythene mulch improved soil moisture retention when applied after early season rainfall or irrigation and caused increases in soil surface temperature of up to 4-5^{0}C. These increases in soil moisture and temperature were associated with increases in Green Leaf Area Index, Green Leaf

Area Duration and standing biomass. Grain yield was increased up to 51.6%, compared to un-mulched plots. Straw mulch increases in yield 14.0 and 20.7% (non-irrigated treatment), compared with the control in 1998 (5.0 versus 4.3 t ha^{-1}) and 1999 (6.2 versus 5.3 t ha^{-1}), respectively. Furthermore, straw mulch appeared to be beneficial for maintaining soil fertility and improving soil structure.

Irrigation improved early vegetative growth and final yields when early season rainfall was unreliable and maize grain yield increased by 39.5 to 59.6% in 1999, compared with the corresponding non-irrigated treatments. Polythene mulch and contour planting combined with early irrigation produced the highest maize yields.

The results are compared with other published work, including research in erosion plots, where the effectiveness of mulches in reducing runoff and erosion has been evaluated.

A cultivation technique combining polythene mulch, straw mulch, contour planting and early season irrigation is considered likely to be highly effective for increasing productivity and improving soil conservation on sloping land. This project is part of a larger programme, which aims to establish and evaluate a demonstration model at a catchment scale for more sustainable crop production systems in the highlands of South-East Asia.

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1.1 Crop Systems and Production in China

China is situated in eastern Asia, bounded by the Pacific to the east. It is the third largest country in the world, next to Canada and Russia and has an area of 9.6 million square kilometres, or one-fifteenth of the world's land mass.

China is mainly an agricultural country, with a total population of 1226.7 million (China Statistical Yearbook, 1997) and a cultivated land area of 131.1 million hectares (Fischer *et al*., 1998). Agricultural problems have long been a major consideration by the Chinese Government. How to produce enough products on China's limited cultivated land to feed the increasing population is the most important matter concerning the government and agricultural researchers. It is necessary to understand the detailed agricultural background and current situation, in order to find suitable development methods. Here is a summary of some of the agricultural aspects connected with agricultural production in China.

1.1.1 General Situation of Chinese Agriculture

China has a long history of development in agriculture. "*Min Yi Shi Wei Tian*" (The Eating is the First Thing for People in a Day) described the importance of agriculture in Chinese daily life. In the long term, agricultural production has been the main activity, engaging about 85% of the total population. Along with industrial development, agriculture is still the main national activity. It is being paid more attention by government, because it affects many social aspects, such as issues of population, natural disasters and urbanisation. Here the main agricultural problems of China are discussed.

<u>1) Rapidly increasing population increases the pressure on Chinese agriculture</u>

During the past 50 years, China has rapidly increased in population. The population increased from 556.7 million in 1950 to 1226.7 million in 1995 (China National Committee on Ageing, 1998). It is predicted to be 1380.5 million by 2010 (Heilig, 1993), which will be one sixth of the total global population. The Chinese

Government has implemented many agricultural policies to encourage crop productivity and many advanced techniques have been used in agricultural production. This has increased the yield per unit area from 1.54 tonnes (1960) to 3.91 tonnes (1998) per hectare, but lack of food is still a major problem (China Yearbook, 1999), especially as frequent, natural disasters cause unreliable crops yields. China had a total domestic cereal production of 388 million tonnes in 1996 (FAO, 1997). However, there was still a shortage of 16.5 million tonnes of cereals (including 10.3 million tonnes of maize and wheat, 6.2 million tonnes of other cereals), which needed to be imported (FAO, 1997).

In terms of crop consumption, there were 237.4 million tonnes of cereals available for direct human consumption in 1996, equivalent to 192.7 kg per person per year, including 84.3 kg of wheat and 92.4 kg of rice. This meant 72% of all cereals available in the country were used for direct human consumption and 18% were fed to animals. More than 5% was wasted, compared with the average consumption in the world of 57.1, 32.5 and 4.5 kg for human, animal feed and waste, respectively. This data clearly indicate that, in China, most crops are used for human consumption (World Bank, 1997). In a country with an increasing population, food requirements have put pressure on agricultural productivity.

<u>2) Limited Available Cultivated Land Increased Agricultural Contraction</u>

There are about 110.1 and 20 million hectares slope and flat cultivated land in China, respectively, according to the 1995 statistical data (Fischer *et al*., 1998), in total about 14% of the total land of China and 7% of the total cultivated land of the world (Wu Bozhi, 1998). Within the cultivated land, about 84% is sloping land. The other 16% of flat land decreases very quickly for the different uses. Per capita cultivated land decreased from 0.18 hectares in 1952 to 0.08 hectares in 1998 (China Statistics Bureau, 1999). According to the statistics of ‘flow-data’ (increase or decline) from 1988 to 1995, the reconstruction of cultivated land area in China has shown a net decrease (Table 1.1).

Table 1.1 Reconstruction of cultivated Land Area in China, 1988-1995 (thousand hectares)

Year	**Total-beginning**	**Increase***	**Decrease***	**Net-change**	**Total year end**
1988	132835.0	372.0	676.3	-304.3	132530.7
1989	132530.6	388.3	417.3	-29.0	132501.6
1990	132501.5	446.2	346.4	99.8	132601.3
1991	132601.4	425.1	448.3	-23.3	132578.2
1992	132578.1	412.4	707.3	-294.9	132283.2
1993	132283.1	302.4	625.3	-322.8	131960.2
1994	131960.4	346.9	785.2	-438.3	131522.1
1995	131521.9	388.9	798.1	-409.1	131112.7

Source: State Land Administration, Statistical Information on the Land of China in 1995. Beijing, 1996.
*** The mainly increase area is highland re-cultivated land.**
*** The decrease included urbanisation, erosion and desertification.**

This shows that even though there was some new land cultivated every year from 1988, more was taken out or lost. In 1995, for instance, China lost some 798,100 hectares of cultivated land: most of it was converted to horticulture, reforestation or lost in disasters (mainly floods and droughts). However, China's farmers also expanded the cultivated land by some 388,900 hectares, mainly by reclamation of sloping areas and deforestation, but also by conversion of areas previously used for other purposes. The net-change of these increases and declines, which amounted to some 409,100 hectares, only slightly reduced the stock of cultivated land (Heilig, 1993).

Per capita land decreased to half the area in 1998 compared with 1952 (0.18 ha in 1952 versus 0.08 ha in 1998). There was a mean decline of 466,700 hectares of cultivated land every year during the past 50 years (Bao Juxiang *et al*., 1999). The cultivated land in China decreased very quickly and China's cultivated land potential is very limited. China has a total of 196.8 million hectares of land which can be cultivated and are mainly located at the high altitude and steep areas (China State Statistics Bureau, 1999). Some 76.7% of the cultivatable land has been used for agricultural production. The remaining 23.3% is marginal arable land, which occupies about 6% of the total area of China. Suitable cultivated land in China is extremely limited.

3) Urbanisation and Agriculture

One of the main causes of the decrease in cultivated land is urbanisation of the countryside. During the past 45 years, the urban and rural population has changed very rapidly. The total urban population increased from 71.63 million (12.5% of the total population) in 1945, to 369.89 million (29.9% of the total population) in 1997 (China Statistics Yearbook, Beijing, 1998). The urban population increased more than five fold during this period. City construction caused much flat cultivated fields to be occupied. During 1988 to 1995, for instance, there were 980,243 hectares of flat fields used for city construction (China State Land Administration, 1996), which occupies 7% of the total paddy-field area of China. Urbanisation seriously threatens agricultural development in China.

4) The Limitation of Climate in Agricultural Development

Owing to its location, China has a climate dominated by East-Asian monsoons and has a great temperature difference between its northern and southern parts. In winter, the prevailing winds blow from Siberia, bringing a cold and dry climate but, in the summer, warm and wet monsoons blow from the south-east Pacific Ocean, bringing a hot and rainy climate to the country. The rainfall is concentrated in July and August. There are major differences in annual average precipitation among different regions. The annual mean precipitation usually exceeds 1500 mm in the south-eastern coastal areas, but gradually decreases to <50 mm in the north-western continental areas (Ministry of Water Resources of China, 2000).

The great differences in climate are found from region to region owing to China's extensive territory and complex topography. This has influenced population density differences. For example, about 50% of the Chinese population in 1992 (or 589 million) lived in some 22.3% of the total land area, in which average precipitation between 1958 and 1988 was >1000 mm per year. The population density in these areas was between 280 and 324 people km^{-2} (Cheng Chunshu, 1993). Because of climate variability and uneven rainfall, Chinese agriculture suffers from different kinds of natural disasters, including drought and flood. According to State Statistics of 1978 to 1997, on average 60.6% the disasters come from drought, which influences 45.6% of the total cultivated land in China. Beside drought, flooding during the rainy season was also a major disaster. It comprised 25.1% of the total disasters (droughts and floods) during the statistical period 1978 to 1997 and accounts for 18.1% of the total cultivated land of China (China Statistical Yearbook, 1997). It is indicated that all agricultural areas in China suffer from disasters, which makes agricultural production unreliable.

5) Land Degradation and Soil Erosion

China has one of the most serious erosion problems in the world, with a large eroded land area. It was estimated that 15.5% of the world's soil erosion occurred in China, on just 7.9% of global cropland. According to the assessment of the Ministry of Water Resources of China (2000), the land affected by soil erosion in China at present is 3.67 million km^2, accounting for 38.2% of the country's total territory. Of the total, the water erosion area is 1.79 million km^2 and the wind erosion area 1.88 million km^2. Soil erosion is widely distributed throughout China. It not only occurs in mountainous areas, hills, sandstorm areas and plains, but also in rural and city areas. The areas in the middle and upper reaches of the Yangtze River, Yellow River, Haihe River, Huaihe River, Pearl River, Songhua River, Liaohe River and Taihu Lake all have comparatively serious soil erosion, especially in the middle and upper reaches of the Yellow River and Yangtze River. But the areas of inland river basins have serious wind erosion and desertification in such areas is increasing.

Early reference to the problems caused by erosion as a result of increasing pressure on land resources in China was made by Thorp (1939), who examined the change in soil properties resulting from long periods of cultivation. He cited three general causes of important soil changes namely, irrigated rice cultivation, the use of fertilisers and manure, and accelerated erosion following the destruction of upland forests and grassland. Min (1941) stated that, although Chinese agriculturists have accumulated much experience and achieved unparalleled success in the utilisation of soil resources, soil erosion has still been occurring at "*an unprecedented and alarming rate during the last few hundred years*."

The rapidly growing population in China and the concurrent need to increase agricultural production to satisfy food demands, have put pressure on marginal areas to be brought into cultivation (China National Committee on Ageing, 1998). In the highlands, this includes sloping land, even steep slopes (>25^o). In 1995, the upland field occupied about 35.09% of total cultivation area, in which steep upland fields takes 15.6% of the total upland area (Liu Liguang *et al*., 1993). Almost 30% of soil erosion occurs on cultivated land, which occupies 14% of the total country (Chen, 1995). Erosion occurs on about 34.26% of the total cultivated land and more than 90% of upland fields totalling 4.65 million ha of hill cultivated land (Wu, 1995). The amount of soil eroded from the cultivated land is 3.3 billion tonnes per year, which is 14.35% of global erosion amount on cultivated land. Erosion can cause as much as 1 cm surface soil loss every year and 40 million tonnes fertiliser (N, P, K) loss (Wu 1995; Liu, 1993). According to the existing policy, arable land with slopes >25^o, common in tropical southern China, should be progressively returned to forest or grassland (China Statistics Bureau, 1999). However, where it still exists, such cultivation is often without the use of soil conservation measures or appropriate agricultural management strategies and consequently soil erosion is accelerated (Chen Minghua *et al*., 1995). How to find sustainable agricultural strategies on sloping land is a very vital concern facing agricultural researchers.

1.1.2 Crop Systems in China

As discussed in Section 1.1.1, China needs to produce enough crop production on 7% cultivated land of the world to feed 17% population of the world’s population. Under this condition, China’s crop systems have their own special characteristics. The crop cultivation potential is certainly one of the most important factors for China's food security. It describes the upper limit for the production of crops under given agro-climatic and soil conditions at a specific level of agricultural technology. Here the main factors that influence the agricultural systems are discussed.

1) Variable Agricultural Productivity in Different Areas

Reported crop yields in the paddy fields are very high, but in the upland area very low. On the uplands fields, because of the steep slopes the fields usually suffer serious soil erosion and farmers rarely apply fertilisers. This contributes to very low nutrient content. In general, crop yields (total of winter and summer season crops) are around 8-10 t ha^{-1} and occupy 14.3% of total cropland in China. The yield of 10-13 t ha^{-1} just takes 5% of the total crop land. Around 80% of crop land just produces <6 t ha^{-1} and these areas are mainly located in the uplands (Bingsheng, 1996). In particular, Chinese people are concentrated in the high soil fertility areas. For example, about 34.7% of the population live on 14.3% of the cropland, where crop yields are 8-10 t ha^{-1}. Furthermore, lack of irrigation limits the development of upland agriculture. Up to 1997, there were 51.24 million hectares of irrigated cultivated land, which is 39.1% of the total cultivated land in China and very little was upland (China Statistics Bureau, 1998). How to maintain the upland crop system is a key element of improving agricultural productivity in China.

2 Intensive Cultivation, Chemical Use and Soil Quality

Intensive tillage is the traditional tillage method and has been over many hundreds of years. There are two probable reasons, firstly, the dense population encourages farmers to use intensive tillage to achieve greater crop production to meet the needs of society. Secondly, per capita cultivated land is limited so that farmers have to intensively cultivate to increase income. Chinese farmers, especially have a long history of using deep (30 cm) tillage. This was encouraged by the Government and researchers for a long period. The potential of damage caused by deep tillage was not realised until more attention was paid by the Government and researchers to the problem of soil erosion (South-West University, 1989).

In Chinese cropping systems, green manure crops are used as sources of nitrogen and organic matter. More straw should be returned to the soil to improve soil structure and control soil erosion, especially as part of reduced tillage systems. Crop residue, however, is removed for fuel or animal fodder for intensive cropping and single rotation serious damaged soil and environmental systems (Cai Zucong, Cao Zhihong, 1997). Paddy soils in the southern provinces pose difficult soil management problems. Intensive cropping of rice, along with tillage of saturated soil, causes serious deterioration of soil structure, in both surface and subsurface horizons. Sloping paddy soil, even where protected by bench terraces, are subject to severe erosion by summer rains and excessive irrigation. Bottomlands, deltas and level plains commonly lack adequate drainage (Sheng and Liao 1997).

Regular chemical fertiliser use began in the 1960s and developed very quickly, with an increased rate of 9.1% per year from 1980 (Zhu Zhongling, 1999). The amount used in 1993 was 331% of 1979. The total chemical fertiliser rates increased from 50 kg ha^{-1} in 1952 to 307 kg ha^{-1} in 1993 (China Statistics Yearbook, 1995). Some statistics analysed the consumption of chemical and organic fertilisers in China between 1952 and 1993. While the use of organic fertilisers was predominant between 1950 and 1960, the use of chemical fertilisers has increased rapidly since the late 1970s. By 1982, Chinese farmers were applying more chemical than organic fertilisers on their fields; by 1993 they were using about twice as much chemical than organic fertilisers (Wang *et al.*, 1995). In the mid-1980s, the total applied amount of chemical fertiliser exceeded the USA and China became the world's largest fertiliser consuming country (Cai and Cao, 1997).

China's crop yield increase depends mainly on the rate of use of chemicals. There was a high correlation between yield and fertiliser use. When other factors were satisfying, the correlation equation is: $Y= -0.0132X^2 + 15.28X + 580.64$ (in which, Y-yield (t ha^{-1}); X-chemical use rate (t ha^{-1}); R = 0.986**) (Wang, *et al.*, 1995). It indicated that crop yield in China mainly depended on chemical fertiliser use, which has a decreasing efficiency of utilisation. Cai *et al*. (2000) investigated the use efficiency of nitrogen and phosphate and found that nitrogen use efficiency in China was <40% while the efficiency of use was 70% in the USA. The wasted part caused serious harm to the soil, environment and water. For phosphates, the absorption rate during the cropping season was <15%, which caused the water and lake pollution with high Excess Nutrient Pollution of Water (Qian Hongqiang, 1998).

Apart from chemical fertiliser, agriculture was swamped by pesticides. According to the assessment, the average amount of pesticide used in the farm was up to 15-30 kg ha^{-1}, some were up to 70 kg ha^{-1}, in 1995 (China Statistics Yearbook, 1995). Use increased after the 1980s, which not only caused serious harm to the environment, but also to human health.

Intensive cropping and intercropping, which the Chinese excel at, benefit to produce a high production on one side. On the other hand, as an agricultural system, China's crop system is complex and fragile. It needs to introduce the sustainable view to establish a system based on the soil, fertiliser, pesticides, planting systems and management methods. The gain in productivity has been very substantial. Erosion has been a major problem on sloping land, but less so on the flat land. On the latter the most serious problem has probably been over use and inefficient use of fertilisers.

1.2 Cropping Systems and Productivity in the Highlands of Yunnan Province

1.2.1 General Situation of Yunnan Province

A frontier province in the south-west of China, Yunnan is situated at latitude $21^0$8'32"-$29^0$15'8" north and longitude $97^0$331'39"-$106^0$11'47" east, with the Tropic of Cancer traversing the south of the Province (Plate 1.1). Yunnan borders Guizhou Province and Guangxi Zhuang Autonomous Region in the east, Sichuan Province in the north, the Tibetan Autonomous Region in the north-west, Myanmar in the west and Laos and Vietnam in the south. Geographically, Yunnan is connected with the rest of the Asian Continent in the north and faces the South-East Asian Peninsula between the Pacific Ocean and the Indian Ocean in the south. Because of its geographical location, the south-east monsoon, and south-west monsoon, as well as weather conditions in the Tibetan Plateau, affect Yunnan. As a result, Yunnan has a diverse, natural environment. The main modifying influence is altitude.

Yunnan Province is near Thailand, Cambodia, Burma and India, with a population of 40.41 million in 1996 and 24 registered minorities (Yunnan Yearbook, 1996) and ranks 8th in the whole country in terms of territory, which is 394,000 km^2 (maximum1864.8 kilometres from the east to the west and 900 kilometres from north to south), covering 4.1% of the whole territory of China. Of the total area of the Province, about 84% are rugged mountains, 10% are highlands and hills and 6% is lowland and valleys (Hao Weiren, 1990). While Yunnan is at an average elevation of about 2000 metres, the elevation ranges between 6740 and 76.4 metres.

Plate 1.1 Location of China and Yunnan Province

1.2.2 Crop Systems and Existing Problems in Yunnan Agricultural Production

There were 6.533 million hectares of cultivated land in 1997, accounting for 4.98% of the total cultivated land of China (China Statistical Yearbook, 1997). The main crops are rice, maize, wheat, root crops, beans and cash crops (tobacco). The main crop planting area in 1998 was 3.18 million hectares with a main crop yield of 12.143 million tonnes. As Yunnan is located in a mountainous region (*Himalayas* and *Hengduan range*), the diverse climate and variable topography make Yunnan suffer more problems than other places in China. Firstly, Yunnan is more mountainous. The mountainous area occupies 94% of its total area. Secondly, Yunnan has problems with increasing population, which puts more pressure on land. Compared with the rest of China, problems with agricultural systems in Yunnan are greater than other areas of China. Besides this, Yunnan agriculture also has its own characteristics. Here the main crop systems and the agriculture problems in Yunnan are summarised.

1) Typical Diversity of the Agricultural System

Under the influences both of natural, geographical and socio-economic conditions, Yunnan agriculture has characteristics typical of mountainous regions in the sub-tropics. Because of the difference of altitude in this region, the natural conditions are very varied, causing considerable differences in agricultural production, especially, with altitude. Generally, according to the changes of elevation, there are three agricultural regions from south to north; namely, the low and tropical agricultural region, the middle temperate agricultural region and the plateau agricultural region. The low and tropical agricultural region is located in the southern part, with an elevation of 1300-1500 m, which occupies 27% of the total area of Yunnan. It is the double-harvest rice, cash crop, tropical forestry and tropical fruit area. The middle temperate agricultural region is located in central Yunnan, some 1300-2300 m above sea level, which occupies 54% of Yunnan. It is the main agricultural area for rice, oil seed and other cash crops with intensive cultivation. This area is the main economic zone in Yunnan. The plateau agricultural region is located in the north-east and north-west of Yunnan at 2300-2500 m altitude, occupying 18.4% of Yunnan. Because of the colder climate, the main crops are tomatoes, buckwheat and oats (Chen Yongsheng *et al*., 1990). It is not possible to apply the same agricultural technologies throughout Yunnan, because of the varying natural situations, industry systems, crop structure and cultivation levels.

Food products industry is the main part of Yunnan agriculture. It occupies 52.3% of the total agricultural output value and 70% of countryside labourers are engaged in agriculture planting (Chen Yongsheng, 1990). Because of the environmental differences, planting skills on farms are very different. Only about 30% of the total cultivated fields are managed properly, with fertiliser and other agricultural skills. Most of the 50-60% of cultivation land cultivated with the traditional hand cultivation and ‘pillage procedure’ production. Furthermore, there are some areas still following the ‘slash and burn’ style, which depends on deforestation to maintain the limited soil fertility (Yunnan Poverty Assistant Office, 1995).

During the past 20 years, the proportion of total agricultural income in Yunnan derived from crop planting has decreased, but it it still plays an important role in

Yunnan agriculture. Planting industry still occupied 70% of total agricultural value in 1995 (Yunnan Provincial Goverment, 1995). The plant products ratio in Yunnan Province is the highest area in southern China. Concerning crops, Yunnan is a major rice-maize production area with 32.3 and 27.0% planting areas allocated to rice and maize. The planting area for rice and maize has a mixed condition because of the variation in climate.

The special geographical location, diverse climate and traditional agricultural methods form the character of Yunnan agriculture. Under this situation, Yunnan agriculture has to face some detrimental conditions.

<u>2) Deforestation threatens the limited rain forest</u>

Tropical and sub-tropical areas are located in the southern part and occupy 15% of Yunnan (Shi Kunshan *et al*., 1999). Because of the abundant rainfall, there Province is rich in rainforests, diverse plants and planting systems. The farmers can plant rice in paddy fields, while on the uplands sugarcane is the main annual crop. Some of the minority nationalities continue the traditional cultivation style, cut down the forest, burn it, plant crops one season then move to other place to continue the same procedure. This has caused large areas of rainforest to be destroyed. During the past 40 years, forest cover in Yunnan declined from about 60% in the 1960s to 24.6% in 1993 (Shi Kunshan *et al.*,1999), while figures supplied by Wang Hongzhong (1999) suggested that tropical forest coverage in *Xishuangbanna* in southern Yunnan declined from 70% in the 1950s to 34% in the 1990s. Shifting cultivation still exists, mostly on hillsides and accounts for the destruction of a further 10,000 ha every year, leading to severe soil erosion (China Statistical Yearbook, 1997). The main problem in this area is deforestation and local farmers have not adapted to the concept of using fertiliser. Some areas still plant 'sanitary crops' (no fertiliser or attention after sowing). The crop yield is very low (2-3 t ha^{-1}), especially in the mountains (Yunnan Yearbook, 1995). How to regulate the planting methods on the upland for the minority people and establish a stable agricultural system are the main tasks in this area (Chen Yongsheng, 1990).

3) Land Degradation and Soil Erosion

Yunnan upland cultivated land takes 84% of the total cultivated land, becoming the fifth serious soil erosion Province in China (Chen Ming *et al*., 2000). According to Remote Sensing Technique statistics, within the 394,000 km^2 Provincial land area, there were 141,333 km^2 affected by soil erosion, some 35.9% of the total area of Yunnan (Chen Ming *et al*., 2000). Concerning the cultivated land, 70% of the total 6.53 million hectares of cultivated field are located in hilly land (Wu Bozhi, 1996). The typical monsoon climate causes rainfall and hot, dry and cold weather can occur in the same period. Heavy rainfall during the rainy season often causes serious runoff, eroding large qualities of organic matter and surface soil. Concerning the cultivated land, some 5,061 million hectares suffered from soil erosion, which occupies 77.5% of the total cultivated area of Yunnan (Yunnan Provincial Government, 1996). Along with the degradation of cultivated land, the production (mean 0.16 ha per capita) cannot match the needs of the increased population. More steep land ($>25^0$) was cultivated to produce more food. There was some new area of 79,000 hectares of uplands cultivated during the period from 1988 to 1995 in Yunnan (Yunnan Provincial Government, 1996). The traditional downslope cultivation on the upland fields produced considerable soil erosion. During a single maize planting season, for example, soil erosion was up to 75 and 225 tonnes ha^{-1} under 10^o and 31^o slope downslope maize planting (Wu Bozhi, 1996). Serious soil erosion influences land sustainability, which is the main problem that Yunnan agriculture must face. How to form a productive and sustainable agricultural environment is a very urgent matter.

Some assessments have stated that Yunnan catchments have undergone substantial deforestation, soil erosion and sedimentation (Whitmore *et al*., 1994). Human activities, especially cultivation, caused a 15-fold increase relative to natural erosion rates of non-carbonate, clastic materials from two small (350 km^2) catchments. Phosphorus export from these catchments increased approximately 19 fold. The degree of human influence appeared to differ between the two larger (2700) km^2 catchments. Accelerated soil and nutrient erosion rates from Yunnan catchments are high, and may ultimately destabilise agricultural productivity and the agrarian economy. Environmental policies are needed to balance ecological constraints with economic activities that impact water quality (Whitmore *et al*., 1994).

4) Crop productivity improvement

The temperate area is the main area of Yunnan Province and the main region of crop production, which occupies 60% of Yunnan Province (Hao Weiren, 1989). This area is the main economic zone of Yunnan Province using intensive cropping methods, intercropping, alley-cropping and intensive cash crop planting. Multiple cropping and intercropping systems are carried out in this area. Triple cropping is common, with rice-rice-green manure, rice-rice-wheat, rice-rice-broad bean in the paddy fields and maize-green manure, maize-wheat, potato-pea, or tobacco-wheat on upland fields. Intercropping systems include maize intercropped with broad beans, peanuts, peppers, eggplant or sweet potatoes and fruit trees intercropped with wheat or vegetables (Chen, 1990).

Concerning the planting area, the main crops are rice, maize, wheat, root crops, bean and cash crop (tobacco). Maize planting areas have been continuously increasing from 1952. With the increased requirement of food from the increasing population, more and more upland was cultivated. The total maize planting in 1998 rose to 1.09 million hectares, which was larger than the rice planting area of 0.92 million hectares (Table 1.2).

Table 1.2 Maize planting area and yield in Yunnan Province from 1949 to 1998

year	Total Cropping Area*	Total crop Yield**	Maize planting Area	Maize Yield	Percentage ***
	Million ha	Thousand Tonnes	(ha)	Thousand Tonnes	(%)
1952	2.23	4016	838300	1017	25.3
1955	2.52	5121	901000	1254	24.5
1960	2.74	4561	924900	1154	25.3
1965	2.76	5493	953900	1459	26.6
1970	2.90	6563	958600	1725	26.3
1975	3.00	7575	953500	2073	27.4
1980	3.16	8241	1110800	2631	31.9
1985	2.90	9001	920300	2488	27.6
1990	2.94	9743	989900	2806	28.8
1998	3.18	12143	1093600	4207	34.6

Source: Yunnan Government, Yearbook, 1989, 1991, 1993, 1995, 1998, 1999. Crop section.
* Total Cropping areas include Rice, Maize, wheat, Root Crop and Bean.
** Total Crop yields include Rice, Maize, wheat, Root Crop and Bean.
*** Maize percentage is the rate of maize take from total crop yield.

Maize plays a very important role in Yunnan agriculture. The occupation of the maize increased from 25% in 1952 to 35% in 1998. Maize was the largest area of all planted crops in Yunnan. Stable maize productivity is beneficial to the development of Yunnan agriculture. Because of simple agricultural techniques, climatic variables and the steep slope condition, even the capita yield increased much from 1.2 t ha^{-1} in 1952 to 3.85 t ha^{-1}, while in 1998, it was still lower than mean unit area yield, the mean maize yield was very low at 3.85 t ha^{-1} in 1998. Maize yield increase and the establishment of stable yield condition are probably the main research targets for the government and researchers.

With the general situation of agricultural production in China, Yunnan faced the problem of depending on chemical fertilisers to increase agro-production. Farmers have to use increasing amounts of chemical fertilisers. The average use rate was up to 306 kg ha^{-1} (the mean use rate in China was 307 kg ha^{-1}) (Wu 1995). In some areas, in order to produce enough yields in the paddy fields, the farmers even use 600 kg ha^{-1} for maize and other cash crops (Xu Xiangyi, 1993). The imbalaced use of chemical fertiliser (include nitrate and phosphate) caused soil compaction, low organic matter content and poor soil structure.

In summary, the agricultural situation and cultivated land potential patterns condition are very clear. Crop yields on sloping land in Yunnan are very low compared with other parts of China. There is still some potential for improving maize productivity by adopting more suitable planting methods. Based on its natural situation, Yunnan upland agriculture faces more problems than other agricultural areas in China, such as climatic variability and soil erosion. Indiscriminate agricultural intensification will accelerate this degradation of a vital natural resource. Rapid industrialisation and urbanisation, coupled to continuing demands for increased food production, will put further pressure on land use and force greater use of these fragile areas. The evaluation of effective methods to improve productivity and establish more stable maize yields is therefore essential for the uplands of Yunnan and all China.

1.3 Sustainable Agriculture

1.3.1 Some Concepts

As a new concept of agriculture, sustainable agriculture, developed very quickly and was paid increasing attention by governments of countries around the world. During its development, many people tried to find the best definition of 'sustainable agriculture.' In some countries it was defined by law. For example, sustainable agriculture was defined in the USA in Public Law 101-624 (Title XVI, Subtitle A, Section 1683, Government Printing Office, Washington DC, NAL KF 1692.831 1990). Under that law the term "sustainable agriculture" means an integrated system of plant and animal production practises having a site-specific application that will, over the long term:

A) Satisfy human food and needs.
B) Enhance environmental quality and the natural resource base upon which the agricultural economy depends.
C) Make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.
D) Sustain the economic viability of farm operations.
E) Enhance the quality of life for farmers and society as a whole.

"Sustainable agriculture is a way of farming that can be carried out for generations to come. This long-term approach to agriculture combines efficient production with the wise stewardship of the earth's resources" (Gregorich, 1995).

According to the above concept, the most important link between farming practises and sustainable agriculture is the health, or quality, of our agricultural soils. If soil becomes degraded, more resources in terms of time, money, energy and chemicals will be needed to produce less-abundant crops of lower quality and the goals of sustainable agriculture will not be met. On the other hand, if soil degradation is reversed and soil health maintained or improved by using appropriate farming methods, sustainable agriculture can be a reality.

Griffith (1998) stated that a "Sustainable Crop Production System" is a term often used to describe a management philosophy that will be adopted by those farmers who are going to remain as the future producers of our food, feed and fibre. This philosophy includes the implementation of crop management strategies that provide:

A) Adequate, high quality food, feed and fibre supplies that are produced economically, and with the added responsibility to safeguard the environment.
B) It is the combination of productivity of field and responsibility of farmers.
C) A sustainable system seems to start with the adoption of Best Management Practises (BMPs). Once in place, BMPs lead to Maximum Economic Yields (MEY) and together they lead to sustainability, both economically and environmentally.

Summarising these concepts of sustainable agricultural systems, when people assess an agricultural system the following steps should be included:

(1) Identify emissions and other releases linked to different crop production practises.
(2) Trace each different release from its source (the crop management practise) to its sinks (i.e. agro-ecosystems and other ecosystems or components of ecosystems directly or indirectly affected by these releases).
(3) Select indicators that adequately describe the condition of the ecosystem affected directly or indirectly by crop production practises.
(4) Determine threshold values for the selected ecosystem indicators (i.e. values which should not be exceeded if irreversible changes in the affected ecosystems are to be avoided).
(5) Transpose the ecosystem threshold values to the farm level by retracing the impact pathways (from Step 2) backward to crop production itself.
(6) Derive farm-level indicators that point to separate or combined agronomic practises that could cause irreversible changes in affected ecosystems.
(7) Determine farm-level threshold values for management-induced releases on the basis of ecosystem-level threshold values.
(8) Identify production schemes that adhere to the framework set by the farm-level thresholds. From these production schemes, the farmer can select those most in line with his available resources and objectives (Lewandowski *et al.,* 1999).

1.3.2 The Potential of Sustainable Agriculture in China

Most definitions of sustainable agriculture include economic, environmental and sociological aspects. A sustainable agricultural system is the combination of animal (livestock), crops and human activities. In China, livestock are usually separated from crops because of land limitations. Sustainable agriculture usually concentrates on crop cultivation and field soil conservation. The finite area of land emphasises the need for consideration of soil conservation and soil quality in relation to sustainability. An important element of soil quantity and quality is rooting depth (Kirkegaard *et al*., 1994). Therefore, loss of soil by erosion is a dominant factor in long-term sustainability. Soil organic matter may be one of the most important soil quality characteristics in relation to tillage, because of its influence on other soil physical, chemical and biological properties. Conservation tillage practises can increase topsoil organic matter content, aggregate stability and cation exchange capacity (CEC) (Salinas *et al*., 1997). However, bulk density and penetrometer resistance are also increased, especially with zero tillage. Although such soil quality parametres may form a basis for describing some of the consequences of particular tillage practises, they do not provide a basis for predicting the outcome, in terms of crop growth and yield. This is both because critical values of soil quality parametres have not been defined and because in some soils biopore formation in zero or minimally tilled land modifies water movement and thus affects root growth and function in the soil. Modern agriculture depends on high inputs of inorganic fertilisers and chemical pesticides for the maintenance of soil fertility and pest control and tends towards monoculture of cash crop varieties that require considerable inputs.

Agriculture in China has changed dramatically since the 1950s. The increase in agricultural production has been due largely to the enhanced use of hybrid seeds and fossil-energy-derived inputs, such as synthetic fertilisers and pesticides. This development has led to a noticeable shortage of major natural resources for agriculture and serious environmental degradation problems. The rapidly increasing population has placed major demands on Chinese agriculture. To meet these challenges, it has been necessary to develop more sustainable and productive agricultural systems. Among the ecological management practises developed and now widely used in Chinese agriculture are: 1) intercropping and multiple cropping, 2) minimum tillage and conservation tillage, 3) application of green manures and other organic fertilisers, 4) water-saving cultivation techniques for rice and other crops, 5) cultivation of common duckweed and/or fish in paddy fields, 6) combined aquaculture and crop production systems, 7) the development of various agroforestry systems, 8) the integrated use of crop residues and other agricultural wastes for cultivating mushrooms and 9) feeding animals and producing biogas (Raimbault, 1992).

In China, concerning sustainable agriculture, some prototype systems emphasise a form of sustainability composed of technical systems for increased water use efficiency for diverse crop products and by-products. The key features of the sustainable prototype system have included selection for: 1) drought resistance crops having low water requirement and high yield potential, 2) intercropping systems with high yields and high benefits, 3) a grain crop yield computer model, 4) nutrient management with emphasis on fertiliser balance and water use efficiency, 5) tillage management and polythene mulching techniques, 6) establishment of water storage tanks for harvesting runoff to provide life saving/critical irrigation, and 7) ammonia-treated wheat straw and silage (maize stem) as livestock forage. Further research is required into techniques for water harvesting and critical irrigation and water budgeting under conditions with different crops and for application of antitranspirants (Song *et al.,* 1997).

Sheng and Lao (1997) reviewed erosion control in South China. They found that locally developed control measures have been applied successfully to reduce erosion, including the benching of steep slopes, construction of check dams and reforestation. Of particular importance is the treatment of large gullies, locally called ‘broken hills.’ These have led to severe erosion of hillslopes and the deposition of colluvium and fines on agricultural land. Gully treatment includes the stabilisation of headwalls, the containment of sediments in the gully floor zone and the reclamation of flatland below the gully mouth. Re-vegetation of the slopes is essential and the planting of economic crops provides incentives to farmers to preserve the vegetation cover.

1.3.3 Approaches to Sustainable Agriculture in Yunnan

1) General Problems

As a mountainous Province, agricultural sustainability is very important. Because of the problems discussed with the use of uplands and potentially high soil erosion, compared with the requirements of sustainable agriculture, Yunnan Province has particular problems in term of improving sustainability.

A. The diversity of soil types, along with low fertility and pH values, cause the advanced techniques to be inefficient in different areas. There are 15 different soil types, but the main type of red earth (Ultisol) soil series (Brick-red soil, red soil and yellow soil) occupies 65% (Chen *et al*., 1989). The pH value is around 5.0-6.5. Most of the main crops are grown in this area. Lack of phosphates, low potassium concentrations and acidity are typical characteristics of Yunnan Ultisols. It is very difficult to adopt sustainable methods on some soils (Hao Weiren, 1989).

B. Climate zoning cultivation causes serious nutrient loss. Among the 94% of upland, the steep land (20-25^0) occupies 15.3% where the topsoil is often highly erodible. Some 55.9% of the total cultivated land has a shallow topsoil cultivated layer (Liu Wenyue, 1993). The low quality of the topsoil on cultivated land is one of the main factors restricting crop yield. Because of the difficulty of cultivating and planting during crop production on steep lands, traditional planting used these areas, even on slope angles >20 degrees. Under such traditional planting and cultivation, 58.6 tonnes ha^{-1} topsoil were washed away, causing 9.6 times more nutrient loss than in flat fields (Liu Wenyue, 1993). Compared with contour planting, downslope planting increased runoff, soil, organic and total nutrient loss by 53.5, 85.7, 84.8 and 84.3%, respectively (Liu Liguang *et al.*, 1991). How to recommend proper cultivation and planting methods are basic problems for establishing sustainable agriculture in the uplands of Yunnan.

C. The limitation of transport and the simple agricultural techniques of farmers are factors restricting the development of upland agriculture. The inputs of fertiliser and improved techniques are very limited. Furthermore, crop stem biomass is often used as fuel, which reduces organic matter re-cycling and leads to unsustainable upland production. The fertile soils are exhausted and there is insufficient fertiliser and surface mulch during the rainy season. The crop yield decreases with the duration of land usage (Fan Yongnian, 1995). Increasing soil fertility and improving soil structure are the main skills to increase crop yields in the uplands of Yunnan.

D. The typical monsoonal climate has four distinct seasons and the main cropping season starts with a very dry spring which influences early crop growth. Soil moisture is the key factor for crop growth. Early spring irrigation is the basis for high crop yields. During the rain season, too much rainfall usually causes serious soil erosion. Furthermore, traditional downslope cultivation enhances this procedure. Research results showed that downslope cultivation caused 2.64 fold increase in erosion, compared with contour planting (Barton, 1999). How to change the traditional cultivation methods is very important to developing sustainable agricultural technology.

2) Some Research on Aspects of Sustainable Agriculture in Yunnan

Soil erosion in an agricultural catchment consists of a natural (geologic) component and an accelerated (human-induced) component. Soil erosion has been a serious problem in Yunnan. The world largest soil erosion flow is located at Dongchuan. As a mountainous province, with a particular climate and diverse soil types, Yunnan is one of the five most serious water and soil erosion provinces in China. Sediment accumulation rates for four main lakes in Yunnan is 15-fold higher than in the 1950s (Whitmore *et al.*, 1994). Accelerated soil and nutrient erosion rates from Yunnan catchments are high and may ultimately destabilise agricultural productivity and the agrarian economy. For a long time, research on soil erosion concentrated mostly on engineering methods and trees planting. There is very little information available, particularly on the accelerated component of soil and nutrient erosion, or its effect on agricultural sustainability in Yunnan.

Since the 1980s, much research has been completed on soil erosion in Yunnan. Wu Bo Zhi and Liu Liguang (1996) stated that contour planting can reduce soil erosion significantly more than downslope planting, and intercropping can significantly increase the permeability rate of water, instead of runoff. In turn, this decreases the loss of nutrients and significantly increases crop yields. Liu *et al.* (1993) stated that downslope tillage and planting caused the highest quantity of erosion with 9.6-24.5 fold increases in runoff and soil erosion, compared with flat fields. The research results have been extended to large scale studies of uplands, combined with international experience on conservation (Fan, *et al*., 1995). Fullen *et al.* (1998) discussed the scale and severity of soil erosion within the headwaters of the Yangtze River in Yunnan Province. They pointed out that the Yangtze River rises in the western uplands of the Qinghai-Tibet Plateau and traverses 6380 km through southern and central China. The headwaters are in tectonically active and geologically unstable uplands. The basin is also generally under intensive agricultural use, mainly for rice cultivation. Hence, erosion rates are high and of increasing concern, especially considering the construction of the Three Gorges (Sanxia) Dam in the middle section (Shi Kunshan *et al*., 1999). Sedimentation within the proposed reservoir could impair its efficiency and therefore soil conservation must be an integral component of basin management.

In 1993, soil conservation efforts in Yunnan were reviewed by the co-operative research team of Yunnan Agricultural University and The University of Wolverhampton, and the local-scale planned approach to soil conservation is illustrated at Xundian as a series of case studies. An ongoing runoff plot study at Yunnan Agricultural University (Kunming) is used to evaluate the effectiveness of various soil conservation measures. Maize (*Zea mays*) cropping treatments, typically employed in local agronomic practises, were applied to 30 erosion plots at three different slope angles, cultivated both parallel and perpendicular to the contour, thus simulating a range of agricultural conditions on arable slopes. Plot data from 1993-1996 suggest several suitable soil conservation measures. Erosion rates were generally lower on plots where contour cultivation was used. The mean contour cultivation erosion rate was 0.69 of the mean downslope orientated cultivation rate. Straw mulch and contour cultivation seem particularly suitable soil conservation measures (Barton, 1999).

Most research is only concerned with one of the aspects of sustainable agricultural systems. This project at Wang Jia Catchment tries to adapt different planting directions, mulching methods and irrigation treatments, to meet the requirement of sustainable high crop yields in the uplands of Yunnan.

1.4 The Maize Crop

Maize is a gigantic, domesticated grass (*Zea mays ssp. mays*) of tropical Mexican origin. The plant is used to produce grain and fodder that are the basis of many food, feed, pharmaceutical and industrial manufactures. Cultivation of maize and the elaboration of its food products are inextricably bound with the rise of pre-Colombian Mesoamerican civilisations. Due to its adaptability and productivity, the culture of maize spread rapidly around the globe after the Spanish and other Europeans exported the plant from the Americas in the 15th and 16th Centuries (Ricardo *et al*., 1997). The global planting area is up to 50 million hectares and world grain yield in 1997 was 589.4 million tonnes (Palmer, 1997).

1.4.1 Maize Growth and Development

An understanding of how maize plants develop can help farmers make important management decisions. As an annual summer crop, maize usually develops 20-21 total leaves, silks about 65 days after emergence and matures about 125 days after emergence. All normal maize plants follow this same general development pattern, but the specific time interval between stages and total leaf numbers developed may vary between different hybrids, seasons, dates of planting and locations (South-West University, 1989).

The staging system employed here divides plant development into vegetative (V) and reproductive (R) stages. Subdivisions of the V stages are designated numerically as VE-emergence, V_1-first leaf, V_2-second leaf, V_3-third leaf, $V_{(n)}$-nth leaf, VT-tasseling. This term $V_{(n)}$ is used, where (n) represents the last leaf stage before VT for the specific hybrid under consideration. The first and last V stages are designated as VE (emergence) and VT (tasseling). The (n) will fluctuate with hybrid and environmental differences. The reproductive stage is subdivided as R_1-silking, R_2-

blister, R_3-milk, R_4-dough, R_5-dent and R_6-physiological maturity stages (Fischer *et al.*, 1984). Table 1.3 describes each growing stage and the days after sowing detail.

Table 1.3 Maize growth staging terminology

Stage	Average number of days/stage	Approximate days from emergence	Stage	Average number of days/stage	Approximate days from emergence
Germination	8	-	Silking	4	69
Emergence	4	-	Silks brown	4	73
First leaf	3	3	Pre-blister	4	77
Second leaf	3	6	Blister	4	81
Third leaf	3	9	Early milk	4	85
Fourth leaf	3	14	Milk	4	89
Fifth leaf	3	15	Late milk	4	93
Sixth leaf	3	18	Soft dough	5	97
Seventh leaf	3	21	Early dent	5	102
Eighth leaf	3	24	Full dent	10	107
$(n)^{th}$ leaf	3	60	Mature	10	131
Tasseled	3	63	Harvest	-	141

Sources: Adapted from Maize Loss Instructions, National Crop Insurance Services (NCIS) #6102 Rev. 1984, 15 pages.

Maize plants increase in weight slowly early in the growing season. But as more leaves are exposed to sunlight, the rate of dry matter accumulation gradually increases.

The physiological understanding of the limitations to grain yield provides a basis for crop improvement, but there are few examples of recurrent selection based on physiological characters that determine yield. Maize has an important part to play in providing food to meet current and future world needs. As a species, it contains enormous genetic variation. The potential yield of maize is larger than that of either wheat or rice and it is expected that maize will assume a proportionally larger and more important role in future world food production (South-West University, 1989).

Although nature provides the major portion of the environmental influence on maize growth and yield, a maize producer can manipulate the environment with proven managerial practises. The practices include tillage, soil fertilisation, irrigation, weed and insect control. Combinations of these practices vary over different production situations and management levels.

During maize growth and development, there are many influencing factors, such as temperature, humidity, soil moisture, soil temperature and soil nutrients. Different factors play different functions at different stages. It is very important to understand these relationships, to conduct proper management in each stage and create a high yield base for maize production. It is also one of the aims of this research project.

1.4.2 Maize Production

Maize is one of the most widely-planted crops of the world. It is produced from 50° latitude N to 40°S, is adapted to arid and high rainfall environments, and to elevations ranging from 0 to 4,000 metres, but mainly at low altitude and tropics with approximately 50 million hectares in the world (Ricardo, 1997). However, about two-thirds of the world's maize is produced in developed countries, whose climates are almost entirely temperate. For example, six nations (USA, China, Brazil, Mexico, France and Argentina) produce 75% of the world's maize supply. The USA alone produces 39-40%, while China grows 18-20% of the total (USDA, 1998). Because of the cultivation condition and technique level, production levels are very different between developed countries in temperate regions and tropical developing countries. Table 1.4 shows the differences in maize planting area and yield in different selected regions and countries.

Table 1.4 Maize area and yield in selected countries and regions (mean of 1996-1999)

Country/Region	Area (Million hectares)	Yield (Tonnes ha^{-1})	Total yield (Million tonnes)	Percentage of world production (%)
World	**139.83**	**4.22**	590.08	**-**
USA	**29.79**	**8.10**	241.30	40.9
European Union	**4.15**	**8.65**	35.90	6.1
China	**24.20**	**4.91**	118.82	20.1
Yunnan	**0.987**	**3.65**	3.60	0.6 (3.0 of China)

Source: Production Estimates and Crop Assessment Division, FAS, USDA, 1998;
FAO Statistical data, 1998,
Yunnan Government Yearbook, 1996-1998.

From Table 1.4, USA produced 40.9% of the total maize yield, using 21.3% area of the total maize planting area, while China has 17.3% maize planting area of the world to yield 20.1% of the total maize grain. The mean highest yield is in the European

Union, where the per unit area yield is 8.65 tonnes ha^{-1}, which are 1.76 and 2.4 fold greater than China and Yunnan, respectively. Although the maize yield of China is a little higher than the mean global yield level, there is still considerable scope for improvement.

1.4.3 Maize Development in China

In China, cereals are used mainly for food, in which agricultural is primarily annual crop production rather than crop and animal production. For example, in 1997, 72% of all available cereals in China were used directly for human consumption and just 18.5% for animal feed (WHO, 1999). It is much higher than the average global consumption of 57.7 and 32.5% for human and animals, respectively. Countries such as Germany, Austria and the USA spend between 60 and 70 % of the domestic cereal supply for feeding livestock (WHO, 1999). Among all the cereal crops, maize plays a very important role. After rice and wheat, maize is the third most important grain in China (WHO, 1999).

In the 1960s and 1970s, between 15 and 20 (5-10 million tonnes imported) million tonnes were used for direct human consumption. Then, in the 1980s, between 20 and 25 million tonnes were used as food. Between 1992 and 1996, the maize supply for food began to decline. In 1996 it was almost exactly at the same level as in 1961. The use of maize as feed grain, however, followed a completely different trend. While in the 1960s, the supply was typically around 10 million tonnes, it increased to more than 120 million tonnes in 1996. China saw a huge increase, especially in 1995 and 1996, in the amount of maize available to feed animals. Obviously, the authorities realised that it was essential to step-up feed grain production, because otherwise the farmers would feed valuable rice to their animals. While in 1961 almost 80% of the maize available in the country was used for direct human food, it was only 10.6% in 1996. In the 1990s, the proportion used to feed animals increased rapidly. This reflects the increase in the consumption of meat, which caused an increase in the demand for feed grain.

Though most of the maize is used as feed grain, it is still the main food in some upland areas. For example, 13.53 million tonnes were used for human food in 1996, which accounts for 10.6% of total maize yield. Furthermore, to meet the needs of the increasing population, there were still about 8-10 million tonnes of maize imported from abroad after the 1990s (e.g. average 8.05 million tonnes over 1994 to 1996) (USDA, 1998). Together with imports and extraction from stocks, the country had a total domestic supply of 140 million tonnes. Despite China's rapid population growth, there was no major change in the amount of maize available for humans (WHO, 1999).

As discussed in Chapter 1.4.1.2, China has 17.3% of the global maize planting area. The yield per hectare was just 4.91 t ha^{-1}, which is just 60.6 and 56.8% of the mean per hectare yield of the USA and the European Union (USDA, 1998). The main reasons are probably the diversity of climates, low soil fertility and lack of production technology. How to improve maize productivity will be a major future task for the Chinese government and agricultural researchers. This project focuses on this productivity issue.

1.4.4 Maize Development in Yunnan Province

As a mountainous province, maize plays a more important part of agricultural production in Yunnan than any other province in China. Next to rice, maize is the main planted crop, which takes 27% of the total cultivated land in Yunnan Province, which is higher than the mean planting area of 18.4% in China (Chen Yongsheng *et al*., 1990). Because of the lack of flat area, maize is mainly planted in the mountains, especially in central, north-west and north-east Yunnan. It was the main daily food for the mountain farmers before the 1980s, accouting for 60% of farmer consumption (Yunnan Government, 1985). After the 1990s, along with the adjusting of agricultural production, maize was mainly used for animal feed. But it is still the staple diet of farmers who live in north-east and north-west Yunnan, accouting for 20% of daily food consumption (Yunnan Poverty Assistant Office, 1995). The main cropping style for maize is intercropping with soy bean, sweet potato, sunflower seeds or pumpkin. Because of the pressure of increasing population, the planting area enlarged from 0.65 million hectares in 1980 to 1.12 million hectares in 1996 (Yunnan Yearbook, 1980 and 1996). Farmers need to cultivate steep areas to enlarge the cropping area to meet food needs, including steep mountain slopes (Wu, 1996).

Yunnan is a multi-national Province. The cultivation skills and traditional planting methods are variable, and the range of climates faced in Yunnan cause maize yields to vary considerably. Generally, maize yield in Yunnan is very low. It fluctuates around 4.0 t ha^{-1} (1995, unit yield was 3.43 t ha^{-1} in the total planting area of 0.989 million hectares in Yunnan). This is less than half of the unit yield of the USA and European Union, as well as only 80% of the average yield of China. Furthermore, frequent natural disasters (drought, flood) made the maize yield vary considerably. It is an important priority to achieve a higher, more reliable level of productivity on sloping land and maintain a stable crop yield and establish a more sustainable crop system in the uplands of Yunnan. This research project attempted to adopt different planting methods to produce high crop yields on upland fields.

1.5 Factors Limiting Maize Productivity

The amount of grain produced by maize will depend upon the rate and length of time of dry matter accumulation. Exploiting this process, linked to optimised partitioning and management, will produce high yield. As a crop system, maize growth is influenced by climate, soil, cultivation, management and variety (Iowa State University, 1993). Some of the conditions are not insurmountable, and maize can recover from shortages, such as spring drought (this is one of the problems in Yunnan which this project aims to overcome). The main factors are concerned with the agricultural technology, such as cultivation methods and management during growth stages. Here is a summary of the main factors influencing maize growth.

1.5.1 Climate

The highest yields will be obtained only where environmental conditions are favourable at all growth stages. The suitable characteristics for maize are high temperature, high moisture and long hours of sunshine. Because of these, the major maize production areas are located in warm, temperate regions. Unfavourable conditions such as dry climate, or low temperatures in early growth stages may slow down the rate of canopy development, limiting canopy size, light interception and dry matter accumulation (Iowa State University, 1993). In later stages, unfavourable conditions, such as lack of sunshine, may reduce the number of silks produced, resulting in poor pollination of the ovules and restricting the number of kernels that develop. Growth may stop prematurely, restricting the size of kernels (Steven, 1982). In Yunnan, early spring droughts are frequent (Yunnan Meteorological Station, 1995). How to supply sufficient soil moisture during the early growth stage is a key consideration for higher yields.

1.5.2 Cultivation and Management

In order to obtain high yields, management of each growth stage is very important. Generally, concerning management during maize cultivation, there are special points which require discussion.

1) Plant density

The optimum plant population is different for different hybrids and in varying environments. If a maize plant is grown under low plant density, it may proliferate by tillering or producing more ears per plant. Increasing the number of plants in a given area reduces the number of ears per plant and the number of kernels per ear. This reduction is greater for some hybrids than others. Grain production per hectare will increase with an increase in number of plants per hectare, until the advantage of more plants per hectare is offset by the reduction in number of kernels per plant (Ricardo, 1997). In the uplands of Yunnan the suitable planting density is 55,000-60,000 plants ha^{-1} (5.5-6.0 plants m^{-2}) (Wu Bozhi *et al*., 1999).

2) Planting methods

Planting methods concern both soil and plant. The different planting methods adopted should be according to the climate and soil. In order to create a suitable circumstance to maintain enough soil moisture, nutrition and temperature, it was suggested that farmers should adopt different planting directions and surface mulch materials. In the long term, planting methods are concerned with soil structure, topsoil depth and soil fertility. In the uplands of Yunnan, the main factors are planting direction and surface mulch. Traditional downslope planting, which was easy to deal with when planting, caused considerable nutrient topsoil loss and most of the straw was used as fuel. To improve planting methods for the Yunnan uplands is also one of the aims of the project.

3) Inter-tillage

Inter-tillage establishes a suitable soil condition during maize growth. It helps maize roots grow well and develop vigorous plant communities (Plant Cultivation, 1989).

4) Crop nutrition and fertiliser application

Maize is a high fertiliser consumption crop. Different nutrition plays its own function in different growth stages. Generally, NPK play particularly important roles. The uptake of potassium is completed soon after silking, but uptake of the other essential nutrients, such as nitrogen and phosphorus, continues until near maturity (Iowa State University, 1984). Much nitrogen and phosphorus and some other nutrients are translocated from vegetative plant parts to the developing grain later in the season. This translocation can result in nutrient deficiencies in the leaves, unless adequate nutrients are available to the plant during that period (Sprague and Dudley, 1988). Maintaining a balance of nutrition in the soil, creating a suitable soil structure and maintaining as much of the topsoil as possible are the main agricultural technologies in maize production. The amounts of nutrients taken up early in the growing season are small, but nutrient concentrations in the soil surrounding the roots of the small plant at that stage must be high. Additional fertiliser can meet this requirement and help stem development and forms a high covering canopy.

5) Control of weeds and diseases

Weeds and disease influence maize growth and yield. Usually, about 5-10% loss of maize yield is caused by disease (Compendium of Maize Diseases. 1995). The weeds compete for soil nutrition and sunshine (Steven, 1993) and the disease directly influences maize growth and the final yield. According to Shurtleff *et al.*, (1993) many diseases, such as bacterial (12 kinds), fungal (74 kinds), mite damage, nematodes parasitic (16 kinds) parasitic higher plant, virus and virus-like (38 kinds) and viral disease (8 kinds) could occur during maize growth. It is necessary to control the weeds and disease.

1.5.3 Soil Physical Conditions

As an environmental factor, soil condition is a very important influence on maize growth. Soil characteristics, such as nutrients, moisture, texture and temperature may affect the length of vegetative stages, but shorten the time between reproductive states. Most of the plant dry weight consists of organic carbonaceous materials resulting from photosynthesis and subsequent processes (Iowa State University, 1984). At least 12 nutrient elements must be taken up for maize plants to grow and develop normally. An adequate supply of each nutrient at each stage is essential for optimum growth (Steven, 1993).

1.5.4 Maize Varieties

Selecting the hybrid best suited to different farm operations is very important. It is well known that hybrid maize varieties have a higher yield potential than native varieties. Because of the diverse climatic zone of upland Yunnan, the best suited hybrid varieties need to be selected according to local situations.

1.6 Methods for Improving Productivity with Soil Conservation Methods

Erosion results in the loss of valuable soil and nutrients, especially organic matter, which is important for good crop production and growth (Cai *et al.*, 1994). There are three main types of erosion, namely, wind, water and tillage (Morgan, 1996). Here, the two latter types of erosion are discussed. Firstly, water erosion may occur gradually during rainfall, or when winter snow melts in fields. It can happen suddenly during floods. Much erosion occurs during the rainy season in Yunnan.

Tillage erosion is mostly caused by the way farmers till the land. The kind of equipment the farmer uses, how often the farmer tills the fields, slope steepness and how the farmer manages the fields during the winter months affect how much soil is eroded. Heavy machinery, frequent tilling and lack of soil cover during winter months contribute to soil erosion. If the slope is steep, all three kinds of erosion may become a problem. Therefore, improved tillage is one of the methods in the uplands to establish stable agricultural systems (Singer *et al*., 1981).

There have been many investigations by agronomists and farmers once the damage of soil erosion have been realised. During the past 70 years, different methods have been adopted in different countries, according to local conditions. Many efficient methods have been achieved and used in crop systems. Generally, ways of improving soil conservation on sloping land include: (1) Mechanical methods to retain soil, (2) Use of different cropping systems, and (3) Cultivation and soil management methods to conserve soil. The last approach can also be used to improve productivity in a selected crop. In reality, most attempts to improve productivity and soil conservation will integrate aspects of all these approaches.

1.6.1 Cropping Systems and Land Use

Conversion of agricultural cultivated land uses is one of the main considered aspects of sustainable agriculture. Rapid growth and escalating land values threaten farming on prime soils. Existing farmland conversion patterns often discourage farmers from adopting sustainable practises and a long-term perspective on the value of land. At the same time, the close proximity of newly developed residential areas to farms is increasing public demand for environmentally safe farming practises. Comprehensive new policies to protect prime soils and regulate development are needed, particularly in upland regions.

Crop or land use cover is an important factor in respect to the sediment production of a catchment (Mitchell, 1979). The main effect of the cover vegetation included:

a) Direct interception of a part of precipitation by vegetation.
b) Reduction of evaporation from soil.
c) Increase of infiltration by opening up soil channels through the development of roots.
d) Depletion of soil moisture by evapotranspiration.
e) Protecting the soil against erosion.
f) Affecting the hydraulic characteristics of surface runoff (Mitchell, 1979).

Proper cropping systems are very important for soil conservation on sloping land. It is one effective agronomic measure for soil conservation using the protective effect of plant cover to reduce erosion (Morgan, 1995). Cropping systems are influenced by many factors.

There are many reviews of the functions of different conservation methods. When crop systems are considered it must be a synthesised system, which includes climate, soil, crop and planting methods. Research has shown that runoff depth, runoff rate, soil loss, and runoff vary significantly by crop stage and year. Runoff depth and runoff rate were correlated with variations in antecedent rainfall, soil moisture, residue and canopy cover. Much of the variation in soil loss appeared to be related to variations in runoff, slope steepness and antecedent rainfall (Mcisaac *et al*., 1992).

Use of steeplands is increasingly common in the tropics and subtropics, because of high population pressures and continuing encroachment on hilly lands, especially in south-western China. Erosion potential and actual erosion in these settings may exceed tens or even hundreds of tonnes of soil loss per hectare per year. Thus, the selection and design of cropping, land management and water management systems must be tailored to attain effective runoff and erosion control, in order to avoid their detrimental impacts, both on-site and off-site. Contrary to the customary arguments for the 'long-term' nature of erosion impacts; enhancing the conservation-effectiveness of rainfed farming on tropical steeplands can provide both short and long-term benefits to the farming system, the overall economy and environment. Productivity-enhancing crop and soil and water conservation management approaches (biological measures) may be more important than structural measures in imparting long-term sustainability (Cogle *et al*., 1997).

It is essential that methods can be found which conserve soil and water during cultivation on steep slopes. Carroll *et al.* (1997) said in central Queensland that wheat lands had significantly lower average annual runoff and soil loss ($P < 0.01$) than sorghum and sunflower. Zero and reduced tillage retained more crop stubble (median >50%) and had less soil loss ($P < 0.05$) than conventional tillage. Zero tillage wheat had the lowest average annual runoff and soil loss and conventional sunflowers had the highest. The erosion risk associated with sunflowers was reduced by a wheat-sunflower crop rotation, particularly when zero-tilled. Thus, mono-culture sunflower must be avoided. The region is susceptible to large episodic erosion when crops are not sown, or there are long fallow or soil cover falls below levels critical for erosion control (<30%).

Development policy is carried out on the assumption that certain land use practises, such as planting rubber in south-west China and fruit trees in northern Thailand, building terraces and planting contour vegetative strips, or conversion of flat land into paddies for wetland rice, are the basis for sustainable land use. Under certain conditions, however, these and similar solutions may actually lead to more problems than they solve (Rerkasem *et al.,* 1995).

Various soil management practises, such as the use of diverse crops, strip cropping, increasing crop cover, multiple cropping, agro-forestry, mulching, conservation tillage, ridging, and furrowing have decreased erosion (Kukal and Khera, 1993). Prato and Wu (1991) reported that these resource management systems decreased total catchment erosion by 67-71%, relative to conventional tillage with contour farming (CTCF) and by 25-33% relative to reduced tillage with contour farming (RTCF). Annual sediment delivery and sediment damage decreased 70% relative to CTCF and 23% relative to RTCF. Sediment damage was 2.5 times greater with CTCF than with RTCF. Total net returns increased 11-16% with respect to CTCF and decreased 1-4% relative to RTCF. In reports from South-Limburg (The Netherlands), Kwaad *et al.* (1998) found that: (a) conservation cropping systems are much more effective in reducing soil loss than runoff on a plot scale, and (b) a surface mulch of straw was the most effective measure to reduce runoff and erosion, by 46.5 and 89.5%, respectively, compared with the conventional system. A study in the Punjab (India) showed that maize at a spacing of 60 x 22.5 cm had minimum soil water erosion rates (Kukal *et al*., 1993). Crops with erect growth and limited tilling allowed higher runoff and soil loss. The intercropping of groundnuts with maize gave the highest net return with the least amount of erosion; maize with urd (*Vigna mungo* L.) gave the second highest net return with the least amount of erosion. Maize and *guar (Cyamopsis tetragonoloba*

L.), in alternating strips of 9 m width, showed minimal runoff (9%) and soil loss (3.3 t ha^{-1}) (Kukal and Khera, 1993).

Cogle *et al.*, (1997) implemented research to improve crop production and land resource protection using innovative soil management practises on Alfisols in India. Their results indicate significant benefits to annual crop yield (maize, sorghum) from improved water supply, due to mulching with farmyard manure and rice straw, and due to rotation with prior-perennial crops. Grain yields were 16-59% higher in mulched treatments compared to unmulched treatments, with similar increases for fodder yields. Annual crop yields after four years of perennials were 14-81% higher than unmulched treatments, except for low fertility maize grown after buffalo grass. The interaction with soil chemical fertility was less clear than for water supply.

The use of winter cover crops in conjunction with minimum tillage may eliminate or at least mitigate the environmental problems associated with traditional maize tillage. Nutrient concentration in runoff was influenced by cropping systems treatments, and was higher without rather than with alley cropping (Lal, 1997). In England, erosion was most common in fields drilled with winter cereals (39% of cases), which was the crop considered by farmers to be at greatest risk of erosion (Skinner, *et al.*, 1996). Estimated crop losses were >10% for only 5% of fields. 'Clean up' costs were incurred on 15% of the fields studied. Farmers considered that the main reason for erosion on their farms was arable cropping and the presence of compacted wheelings/tramlines. Field slope alone was not found to be a major factor in the occurrence of erosion, with almost 60% of erosion events on slopes of $<7^0$ (Skinner *et al.*, 1996). Gumbs *et al.* (1993) reported in the Caribbean that a high percentage of the land has slopes $>20^0$. In these circumstances, tillage is carried out with hand tools and frequently combined with conservation contour drains and/or barriers of cut vegetation laid across the contour. Many farmers form ridges and furrows on the contour with hand tools and a significant number do not use any conservation measures.

Soil management aims to maintain soil fertility and structure. Soil fertility can thus be seen as the key to soil conservation. One way of achieving and maintaining fertile soil is to apply organic matter. This improves soil cohesiveness, increases water retention capacity and promotes a stable aggregate structure (Morgan, 1995). When managed to maintain their fertility, most soils retain their stability and are not adversely affected by standard tillage operations. Indeed, tillage is an essential management technique, as it provides a suitable seed bed for plant growth and helps to control weeds (Pidgeon and Soane, 1978).

1.6.2 Mechanical Methods to Retain Soil

Mechanical field practises are used to control the movement of water and wind over soil surfaces. A range of techniques is available and the decision as to which to adopt depends on whether the objective is to reduce the velocity of runoff and wind, increase the surface water storage capacity, or safely dispose of excess water. Mechanical methods are normally employed in conjunction with agronomic measures. Major mechanical soil and water conservation measures include contour bunding, graded bunding, bench terracing and conservation bench terracing (Sharda, *et al*., 1994; Morgan, 1995).

1) <u>Ploughing</u>

Ploughing is the process of cutting loose, granulating and turning over the soil. These actions greatly reduce the soil's overall resistance to detachment, through destruction of the soil structure and organic matter (particularly live and dead roots) which bind soil particles together. This is to allow for seasonal variations in weather, possible progressive changes in soil conditions and the learning phase experienced when new tillage methods are used. While there is a good deal of variation in the results of these tillage experiments, some patterns have emerged. There has been much research concerned with tillage methods with crop growth, soil structure and soil erosion.

Tillage procedures can be divided into two main kinds, conventional tillage and conservation tillage. For conservation tillage, it includes many methods, such as no tillage, strip tillage, mulch tillage and minimum tillage (Morgan, 1995).

Survey information on tillage practises needs to be considered in relation to predictions on suitability of conservation tillage based on experimental results. In the semi-arid prairies of Canada there is a trend toward fewer cultivation operations, but in eastern Canada the mouldboard plough is still the dominant tillage method (Cannell and Hawes, 1994). In Northern Europe, although erosion is less obvious, it is believed to be increasing, but minimum tillage is not widely used. This is because of the need to remove at least some straw for successful minimum tillage in sequential winter wheat and barley crops. However, there are few economic uses for straw and burning is illegal in many countries. In the more moist cooler conditions of Northern Europe, grass weed proliferation is another constraint, at least with current technology. So far, the overall success of conservation tillage has not been limited by the growing problem of genetic resistance of weeds to herbicides. Societal attitudes to the continued use of herbicides may pose longer-term problems for some conservation tillage practises (Cannell and Hawes, 1994).

Tillage can also improve soil structure. Chisel ploughing and subsoiling, deep tillage practises (whose actions extend below the usual depth of disk ploughing), usually decrease mechanical impedence, improve root penetration and increase crop yields (Aleger *et al*., 1991). No-till seedbeds have the highest soil moisture contents, the lowest proportion of fine soil aggregates (<5 mm diameter) and the greatest penetrometer resistance (Vyn *et al*., 1998). Tillage systems significantly affect soil bulk density in the 0-200 mm soil depth. No-tillage bulk densities ranged from 5 to 19% higher than for the other tillage treatments, while those from moldboard ploughing ranged from 7 to 21% less (Salinas and Garcia, 1997). The amount of elongated transmission pores (50-500 μm) also increased in minimally tilled soils. The resulting soil structure was more open and homogeneous, thus allowing better water movement, as confirmed by the greater hydraulic conductivity (Salinas and Garcia, 1997). Aggregate stability was less in the conventionally tilled soils and resulted in a greater tendency to form surface crusts and compacted structures, compared with the minimally tilled soils Minimum tillage had significantly faster ponded infiltration than chisel or moldboard, as well as greater aggregate stability and less bulk density because of reduced surface sealing (Logsdon *et al*., 1993).

Hermawan and Cameron (1993) researched the effects of conventional tillage (CT) and minimum tillage (MT) on the stability of soil aggregates, pore-size distribution, bulk density, infiltration and penetration resistance. These were assessed after more than 10 years of crop production on a silt loam soil in Canterbury, New Zealand. Results show that detrimental decreases in aggregate stability occurred if the soil was cultivated annually. Conventional tillage slightly increased total and macro-porosity at cultivation depth. Below this depth, however, this practise resulted in soil compaction, as indicated by lower soil porosity, higher bulk density and higher penetration resistance than those under MT. No significant differences were found in infiltration rates. Soil bulk density, porosity and water content were significantly affected by the different tillage systems and contour ploughing (Pearson *et al*., 1991).

Soil loss from cropped land was usually greatest under conventional tillage, unless mulch was applied to the soil surface (Aleger *et al*., 1991). Minimum tillage management of row crops usually reduced erosion compared with systems involving more frequent or more extensive tillage (Kort *et al*., 1998). Thapa *et al*. (1999) studied the tillage-induced soil translocation on an Oxisol with 25% and 36% slopes in Claveria, The Philippines, for three tillage systems. They were contour mouldboard ploughing (CMP), mouldboard ploughing up and downslope (UMP) and contour ridge tillage (CRT). The results showed that the mean displacement distance, mean annual soil flux and mean annual tillage-induced soil loss for both slopes were reduced by ~70% using CRT, compared to CMP and UMP. In China, minimum tillage and no-tillage have been broadly used in modern Chinese agricultural production in the past 20 years (Tang and Zhang, 1996). The application area has reached 12.34 million hectares, and maize, soybean, rape, wheat, peanut and rice crop have been used in these tillage systems. These techniques have provided obvious benefits for soil and water conservation on sloping farm-land in the hilly regions and obtained remarkable effects of storing water and reducing drought in the dryland farming regions. There has also been some success in the reclamation of saline soils.

The common characteristics in different regions are building a good agro-ecological environment, improving soil physical properties, enhancing water storing capacity, regulating the activity of soil micro-organisms, improving the accumulation of soil organic matter, nutrients and fertiliser. In comparison with the traditional tillage systems, soil and water conservation losses were 40-90% less (Tang and Zhang, 1996). A combination of mulch and tillage further reduced soil losses. Contour cultivation reduced soil loss from 6.3 to 2.9 t ha^{-1}, as compared to slope cultivation (Kukal and Khera, 1993).

Conservation tillage may concentrate organic matter and carbon in the soil, thus improving soil quality and counteracting CO_2-increases in the atmosphere. Some research results showed that tillage had no effect on the amount of crop residues returned to the land, but the tilled systems had significantly ($P < 0.05$) lower total organic C and N in the 0-7.5 cm soil depth, but not in the 7.5-15 cm depth (Campbell *et al*., 1998). Generally, soil quality attributes were greater in no-tillage (NT) systems than in conventional mechanical tillage (CT) or minimum tillage (MT), and greater in continuous wheat (*Cont. W*) than in fallow-wheat (F-W) systems. Campbell *et al*., (1998) cited that after a period of five years, reducing tillage through adoption of minimum tillage (MT) or zero tillage (ZT) practises increased total P in the surface 10 cm by 15%, compared to conventional tillage (CT). Although there were no differences in amounts of total P between MT and ZT systems, under ZT management, larger amounts of labile organic and inorganic forms of P accumulated close to the soil surface, followed by a reduction below the 6 cm depth. Under MT, the labile organic and inorganic forms of P were uniformly distributed within the surface 10 cm of soil. Salinas *et al.* (1997) compared N and P nutrition using different tillage methods. The results showed that conservation tillage treatments (NT and MT) resulted in a 30-135% increase in surface crop residues compared with other tillage treatments, while plots with the high N rate exhibited 8% more residue than with low N fertilisation. Residual NO_3-N to a depth of 1.2 m under NT and MT was consistently less than with the other tillage treatments.

Higher levels of soil organic C, total N and extractable P and lower concentrations of NO_3- were directly related to surface accumulation of crop residues promoted by conservation tillage management. Soil inorganic N, soil microbial biomass C (SMBC) and potential C and N mineralization were usually highest in soils under NT, whereas these characteristics were consistently lower throughout the growing season in soils receiving MB tillage. Nitrogen fertilisation had little effect on soil inorganic N, SMBC and potential C and N mineralization (Salinas *et al.*, 1997).

Salinas *et al*. (1997) studied the soil organic carbon (SOC), soil microbial biomass carbon (SMBC) and N (SMBN) under different tillage methods and found that No-tillage and MT retained more maize residue C input as SOC and SMBC than the more intensive tillage systems. Soil organic C, SMBC, SMBN and mineralizable C and N were greatest in the surface 0-50 mm with NT and MT. Seasonal distributions of SMBC and mineralizable C were consistently greater in reduced-tillage systems (NT and MT), averaging 22 and 34% greater than ploughed treatments at planting, 45 and 53% larger at pollination, and 36 and 34% higher at harvest, respectively, at 20 cm depth. Another study found that after 20 years of shallow cultivation, SOC, soil nitrogen and microbial biomass carbon were concentrated in the top 5 cm of a loess-derived silt loam (Salinas *et al*., 1997(a)).

Soil moisture is a most important effect of the climatic system on the land. It affects not only vertical fluxes of energy and moisture, but also horizontal fluxes of moisture, namely runoff (Delworth *et al*., 1989). Tillage is one of the most effective actions to affect soil moisture. Miller *et al.,* (1999) reported that plant-available water-holding capacity was higher for the conventional tillage (CT) field (14.3%) than the no-tillage (NT) field (10.8%), and a greater amount of water was held at a given water potential (-1500 to -1.5 kPa) for the former, indicating a higher potential for soil water conservation under conventional tillage. Zero tillage can increase soil moisture in the spring season. Ekeberg *et al*. (1997) conducted a study comparing zero tillage (ZT) with conventional tillage (CT) crop production in two rotations (fallow-oilseed-wheat and oilseed-wheat-wheat during 1979-1990). In 36 comparisons of ZT with CT over three rotation phases and 12 years, ZT increased spring soil moisture in nine cases and resulted in no decreases; and increased moisture use efficiency in six cases with two decreases.

It is well know that tillage directly influences soil properties and crop yields. In long-term experiments, yields of maize in Europe and the USA and soybeans in the USA have been similar after ploughing and no-tillage, especially on well-drained soils (Cannell and Hawes, 1994). In Europe, yields of winter cereals have also been similar after traditional and simplified tillage, but yields of spring cereals have sometimes been less, after direct drilling than ploughing. Conservation tillage in the USA is increasing and is used on ~30% of cropland, including no-till on ~10% of cropland (Cannell and Hawes, 1994). This increase in the use of conservation tillage is mainly attributed to the legal requirements for farmers who are in government price support programmes to adopt conservation plans involving conservation tillage. However, the allowable rates of erosion in these plans are likely to exceed tolerable rates of erosion for long-term sustainability. After recognising the relationship of tillage with water erosion, many farmers now adopt conservation tillage. For example, in Florida crop preparation and conventional tillage (two or more cultivations prior to sowing) were used on ~66%, minimum tillage was used on 19% and direct drilling used on 16% of farms (Pagliai *et al*., 1995). Generally, conservation tillage practises (commonly referred to as no-till or minimum till) had higher soil surface bulk densities, lower macroporosities, infiltration rates and crop yields compared with conventional tillage, which was typically disk ploughing (Aleger *et al*., 1991).

Ruegg *et al*. (1998) showed that, averaged across the five environments tested, dry matter and nitrogen yields of maize were highest under tillage and lowest under minimum tillage (MT). These differences occurred as early as the 3rd leaf stage and remained until the end of the maize growing season. Total yields of dry matter and nitrogen (maize) of the MT system tended to be higher than the dry matter and nitrogen yields of maize in the other systems. Ekeberg (1997) found the yield of cereals (*Hordeum vulgare L.*, *Triticum aestivum L. and Avena sativa L.*) and potatoes (*Solanum tuberosum L.*) showed consistent increases of 2-8% with declining tillage intensity. Average yields for these crops were 23, 52 and 59% higher with deep tine cultivation, shallow tine cultivation and minimum tillage, respectively, than with plough tillage. In comparison with the traditional tillage systems, crop production increased by 10-20% (Tang and Zhang, 1996). Bonfil *et al*. (1999) found yields of dryland crops in semi-arid and arid zones are limited by precipitation. In drought years, non-tillage management increased yields by 62-67% for wheat-fallow and by 18-75% for continuous wheat, relative to conventional tillage management. During the two years when water deficiency occurred during the grain-filling stage (1994 and 1997), NT management increased grain weight by 20% and test weight by 5-7%, in addition to the 70-200% increase in the total grain yield, relative to CT management.

Some reports show the contradictory results that zero-tillage can lead to progressive improvement in soil nutrient status, but has little or no effect on crop parameters (Almendros, 1998) or provides consistent advantages in grain yield compared with conventional till. Zero till also out yielded reduced till, as well as conventional till. The average yield increase of 0.5 t ha^{-1} in zero till, compared with conventional till, was associated with greater water use and increased water use efficiency. Tillage practise caused only marginal differences in available water content in the root zone (0-100 cm) at sowing; zero and reduced till contained, on average, an additional 4 and 8 mm, respectively, compared with conventional till (Lawrence *et al*., 1994).

Different tillage methods use different machinery or tools. The cost of different tillage operations varies greatly. The profitability of tillage is a major factor governing the adoption of soil conservation practises. Under conditions of similar crop productivity and input (i.e. fertilizer and pesticide use), tillage costs become the key determinant of profitability. Sijtsma *et al*. (1998) compared tillage costs for crop rotations utilising minimum tillage on a farm scale in Canada. Replacement of the mouldboard plough with various combinations of alternative tillage systems (e.g. chisel plough, disc harrow, power harrow) provided annual tillage cost savings of 44-60% for the three-year potato rotation and 10-40% for the barley-soybean rotation. Replacement of the mouldboard plough with various combinations of alternative tillage systems (e.g. chisel plough, disc harrow and power harrow) provided annual tillage cost savings of 44-60% for the three-year potato rotation and 10-40% for the barley-soybean rotation.

Lafond *et al*. (1993) compared the net return of different tillage systems. Results suggested that net returns were similar for winter wheat grown on stubble and for spring wheat grown on fallow for all tillage-management systems. Fuel consumption was highest for conventional tillage (CT), intermediate for minimum tillage (MT) and lowest for zero tillage (ZT) for all crops, except winter wheat. In contrast, herbicide use was greater for ZT and MT than for CT for all crops, except winter wheat. No differences were observed among tillage systems for this crop, because it was always seeded directly into standing stubble. The shift from CT to ZT or MT systems did not increase production costs or reduce short-term economic returns. ZT and MT had higher production potential than CT, because increased soil-moisture conservation generally provided higher net returns. ZT used less fuel but more herbicides than MT and CT. Minimum tillage was the most cost-effective means of conserving soil (Cogle *et al.*, 1997).

2) Bunding

Bunding is used to contour bunds and earth banks. Usually built 1.5-2.0 m wide, they are thrown across the slope to act as a barrier to runoff, to form a water storage area on their upslope side and to break up a slope into segments shorter in length than is required to generate overland flow. They are suitable for slopes of 1-7^0 and are frequently used on smallholdings in a strip-cropping system, being planted with grasses or trees (Morgan, 1995). The banks, spaced at 10-20 m intervals, are generally hand-constructed. There are no precise specifications for their design and deviationsin their alignment of ≤10% from the contour is permissible (Morgan, 1995).

There are many reports about the effects of the bunding. Hurni (1984) calculated the effectiveness of contour bunds to control erosion in Wallo Province, Ethiopia, and showed that they only reduced soil loss sufficiently on the lowest of the slopes examined. The percentages of soil loss stored were 100, 51, 42 and 36% on the 6, 14, 27 and 33^0 slopes, respectively, with 20 cm high bunds. Pathak *et al.*, (1987) found contour bunding of an Alfisol at the ICRSAT Research Centre near Hyderabad, India, reduced annual soil loss from sorghum and pearl millet, both intercropped with pigeon pea, to 0.97 t ha^{-1} compared with 4.79 t ha^{-1} for flat cultivation with field bunds. Research by Kukal *et al*. (1993) on sloping lands with contour bunding in India, showed that it decreased soil loss from 2.56 t ha^{-1} to 0.59 t ha^{-1} and increased wheat yields >20%. Another bunding technique is the use of compartmental bunding, by Selvaraju (1999) on Alfisols and Vertisols of southern peninsular India. Results showed that bunds of 15 cm height formed in all the four sides to form a check basin of 6 x 5 m size, stored 22% more soil moisture and increased the yield of sorghum + pigeon pea intercropping more than traditional practise in a low rainfall year.

3) Hedgerows

Hedgerows are one of the most efficient soil conservation methods on upland fields. It not only can form a micro-climate suitable for crop growth, it can also prevent water erosion and can provide forage for animal feeding. A field experiment tested these soil conservation technologies from 1995-1998, in a randomised block design using hedgerows on a 42% natural slope on sloping volcanic ash-derived Philippine soils (Poudel, *et al*., 1999). The greatest annual soil loss (65.3 t ha^{-1}) was in the up-and-down system and the comparative value was 45.4 t ha^{-1} for high-value contour hedgerows. In the contour hedgerow treatment, rapid terrace development changed soil properties and crop yields. For the bottom, portions of bioterraces yield were 121% greater for maize and 50% for tomato compared with upper portions. Sharma *et al.* (1999) reported in arid India that runoff volume and specific peak discharge were reduced by 28-97% and 22-96%, respectively, using contour vegetation barriers (CVB), with negligible soil loss. The resultant increase in soil moisture storage increased pearl millet crop yield by 35%. At an optimum simulated vertical spacing of CVB between 0.5-0.6 m, 24% reduction in runoff resulted in a better moisture regime and crop yield improvement by 70% over the control. Hedgerows also are widely used in the arid climatic zone to reduce evaporation and retain soil moisture. Sharma *et al.* (1997) found that the 2.5 fold increase in soil moisture storage increased clusterbean crop yields by 37-51%. These barriers are inexpensive and acceptable to farmers in the Indian arid zone. Another effect of hedgerows is to form mature ridges, which are useful to the terrace. Vetiver grass was planted along the contour on a 25^0 slope field. After three years, a 25 cm high ridge formed. The terrace formed kept the soil in a natural layer sequence, which maintained the surface soil structure, especially when the topsoil was very thin (Huang *e tal.,* 2000).

On arable land, grass ley set-aside is one useful method for soil and water conservation. Mean SOM content increased consistently and significantly on set-aside plots in the UK, by a mean value of 0.39% in two years and 0.78% in four years. Soil erodibility significantly decreased. Using grass leys for set-aside could prove a viable soil conservation technique. Grassland could also be used as `soakaways' in arable systems; braking, filtering and infiltrating runoff, thus decreasing net sediment transfer downslope (Fullen, 1996).

4) Terracing

Terraces are earth embankments constructed across the slope to intercept surface runoff and convey it to a stable outlet at a non-erosive velocity, and to shorten slope length. They thus perform similar functions to contour bunds. They differ from them by being larger and designed to more stringent specifications. Decisions are required on the spacing and length of the terraces, the location of terrace outlets, the gradient and dimensions of the terrace channel and the layout of the terrace system (Morgan, 1995). In the uplands of Yunnan Province, terraces are widely used (Yang, 1997).

Bench terracing proved to be more suitable for land with slopes between 6-33%. Structures such as waterways, drop structures, and control dams reduced sheet, rill, and gully erosion from 80, 11, and 3.6% to 15, 2, and 0%, respectively (Kukal, *et al*., 1993).

Mallappa *et al* (1992) investigated the impact of soil and water conservation at Dharwar, India. They found that studies on soil moisture, growth and yield of rabi sorghum revealed the soil moisture was more in levelled portion of zig-zag terrace, graded zig-zag terrace and contour border strip treatments.

1.6.3 Soil Cultivation, Planting and Crop Management Techniques

When crop management is discussed, it is often focused on an exact climatic zones and soil types. During this condition, crop management methods (planting direction, mulching and irrigation) have greater effects on crop production.

1) Planting

There are many different planting methods on upland fields. Usually there are three main methods; namely, contour planting, downslope planting and scatter planting. The farmers adopt the chosen method according to the crop and slope steepness. Considering the effects on crop production, contour planting is the superior method, but it is sometimes difficult on steep slopes. Poudel *et al.* (1999) found that plant height, total dry matter production and its distribution into leaf, stem and reproductive parts, leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), net assimilation rate (NAR) and specific leaf weight were significantly higher in contour border strip, *zig-zag* and graded *zig-zag terraces*. These methods increased grain yield by 103.6, 105.0 and 94.8% during the first year and 101.8, 112.4 and 110.5% during second year over the control, respectively. Crop yields on contour planting were 40% greater for tomatoes (*Lycopersicon esculentum Miller*), 36% for maize (*Zea mays L*.), and 78% for cabbage (*Brassica oleracea var, capitata L*.) than for downslope planting.

2) Mulch

One of the best ways to reduce evaporation is to protect the soil surface with a cover of growing plants or crop residues. Surface cover cushions the impact of rain drops, so soil particles are not as easily dislodged and moved. It also slows the flow of water, giving the soil time to absorb more water and thereby reducing runoff and erosion. A study in Alberta has shown increased infiltration (Ji Zenshun, 1995). Also, crop residues trap snow and reduce evaporation. This encourages higher soil moisture, which can improve crop yields, especially in dry years. Mulch has some additional advantages, namely, increased surface moisture storage, decreased runoff, improvements to soil structure and porosity and improved soil biological activity (Lal, 1976). There are different covering materials, such as natural mulching material (straw, leaf and crop residue) and synthetic mulch materials (e.g. polythene and geotextiles).

(i) Polythene Mulch

Polythene mulch is effective in increasing soil temperature and maintaining soil moisture, especially when soil moisture is insufficient at the sowing stage. Plastic mulches increased soil temperature, induced faster plant growth and earlier fruiting, reduced phosphorus concentration in leaves and fruits and increased nitrogen concentration in leaves and fruits. Yield and mean fruit weight of healthy fruits were increased and earliness of harvesting enhanced (Cross *et al*., 1998). Liu Zhenyu *et al*., (2000) studied the effect of different mulch methods with whole maize straw in dry land on maize yield in Shanxi Province, China. The results showed that the yield of straw combined with polythene treatment was 36.0-54.5% higher than the control.

Plastic mulch improved crop performance and production with increased fertiliser efficiency and evaporation control, making plastic mulches suitable for use in integrated crop management (Vos and Sumarni, 1997).

In many parts of Yunnan, clear polythene mulch is used to improve yields of tobacco, maize and other crops, primarily because of its beneficial effects on soil moisture and soil temperature (Peng, 1990). A 90% cover of black polyethylene was effective in conserving moisture and increasing maize yield and water use efficiency, compared to conventional practise. Peng (1990) attributed this to two factors. Firstly, the polyethylene mulch increased soil temperature, an important consideration in temperate climates, as in their study. Measurements made during the season showed that mean soil temperatures at 30 cm depth were 23.1 and 21.8^{0}C for the mulched and unmulched plots, respectively. However, as the maize developed, the temperature differences between treatments decreased. The second factor explaining the better maize response was more efficient utilisation of light rains, where the mulched plot exhibited deeper penetration of moisture compared to the conventional plot. Decreased evaporative losses from the mulched plot would have assisted in creating a better moisture regime. Such an effect was shown in a parallel laboratory study where, after 70 days, cumulative evaporation under the conventional practise was more than double that from the mulched plot. Although plant height was measured on the plots and rapid and vigorous early maize growth was observed, the actual data were not reported (Willis, 1963).

Griffin *et al*. (1966) conducted a similar study to examine the effects of plastic film, asphalt film and asphalt coated paper on grain sorghum yields in Oklahoma, USA. Soil temperatures were not taken into consideration. The plastic film treatments included 100 and 80% soil coverage. Irrigation water (20 cm depth) was applied before treatment. In the case of the 100% cover, no irrigation occurred after treatment application, whereas with 80% cover, soil moisture supply was immediately re-established by irrigation when plants exhibited first visual symptoms of plant stress. They found that 100% soil coverage with plastic film was effective in reducing surface evaporation. This minimised consumptive water use and increased water use efficiency, thus giving better sorghum yields. Partial soil cover at 80% proved equally effective in the same respect. Although their measurements were taken over two years (1963 and 1964), only the 80% coverage treatment was tested in both years, therefore the results have limited applicability.

Wang Dexuan and Liang Yinli (1989) observed increased soil temperature under polythene mulch in north-west China. They stated that evaporation was reduced and soil temperature and soil nutrients increased, with a consequent increase in wheat yield, under clear polythene mulch. Black polythene mulch increased average soil temperatures by 1.6^{0}C under pineapples in Hawaii, due to enhanced soil thermal conductivity and more effective entry of heat into the soil beneath the mulch (Gill *et al*., 1996). However, soil moisture results were inconclusive, because of large sample variability, although crop growth under the mulch was 20-30% greater than unmulched areas. This enhanced growth contributed to the rapid formation of a full canopy cover and thereby reduced potential soil and water losses, compared to the slower developing canopy on the unmulched plots.

<u>(ii) Straw Mulch</u>

Use of rice and wheat straw as mulching material is very easy and inexpensive. Usually, there are abundant straw materials in agricultural countries. In China, more than 500 million tonnes of straw are produced each year (Gao Tengyun, 2000). How to put it to good use for soil structure improvement and enhance the crop productivity requires further research. Acharya *et al*. (1998) reported that mulches resulted in 0.06-0.10 m^3 m^{-3} higher moisture in the seed-zone when wheat was sown, compared with the conventional farmer practice of soil tillage after maize harvest. Mulch-conservation tillage treatments favourably moderated the temperature and moisture regimes for a wheat crop. The mean root mass density under these treatments at wheat flowering was 1.27-1.40 times higher over the conventional farmer practice during the three year study.

Covering with straw and recycling available organic materials may help enrich the soil environment in the long-term. Straw mulch conserved more water in the soil profile during the early growth period compared to no mulch. A study at tropical Bay Islands, India showed that among the various mulches, rice straw gave 52.11% higher maize yield compared to the control (Pramanik, 1999). Another research implied by Lui Zhenyu *et al*. (2000) found that straw mulch increased yield 40.8% more than control. The yield increase was due to better crop growth parametres, improvement in moisture-stress indices, efficient root development, conservation of more residual soil-moisture in the crop root zone and higher water-use efficiency. Straw mulch conserved more water in the soil profile during the early growth period compared to no mulch (Rathore *et al.*, 1998).

In China, readjusting crop structures and rotations to fit changes in soil water, increasing soil water resources, reducing soil water evaporation and managing soil water to meet temporal and spatial crop water demands are the four main aspects management of soil water (Jin *et al*. 1999). They recommended possible space dimensions and readjustment of crop distribution, in order to harmonise crop water demand and soil water availability. Their studies show that temporal and spatial management of soil water can significantly increase water use efficiency (WUE). For cotton, adopting an integration of micro-topography and plastic mulch increased WUE from 0.49 to 0.76-0.86 kg m^{-3}; stalk mulch with manure for winter wheat reached 2.41 kg m^{-3} and straw mulch with deep furrows (micro-topography) for summer maize increased from 2.06 to 2.34 kg m^{-3} Maize grain yield was significantly affected by mulching in one out of three seasons and was highest at 5.4 t ha^{-1} for 4 t ha^{-1} mulch rate and the lowest at 3.5 t ha^{-1} for 1 t ha^{-1} mulch rate, a difference of 54%. Soybean grain yield was significantly higher at 1.4 t ha^{-1} for 4 t ha^{-1} mulch rate than 0.8 t ha^{-1} for 1 t ha^{-1} mulch rate, a difference of 62.5%. Mean cowpea yield was the highest at ~1 t ha^{-1} for 4 t ha^{-1} mulch rate and the lowest at 0.7 t ha^{-1} for unmulched plots. Meanwhile, runoff and soil erosion were lower in 1981 than in 1984, with higher losses generally for the plough till treatment (Lal, 1998).

Mulch also improved rooting by influencing the soil moisture and temperature regime. Better rooting with deep tillage and/or mulch helped the crop to extract stored soil water more efficiently, which was reflected in a favourable plant water status (indicated by canopy temperature). Crop response to deep tillage and mulching was generally linked to the interplay between water supply (rain + irrigation) and demand (seasonal evaporativity) during the growing season (Gill *et al*., 1996). The effect of straw mulch was simulated simply by decreasing soil evaporation and this resulted in higher levels of soil water and decreased nematode inhibition of rooting. Good agreement was obtained between the three seasons of experimental data and simulations of the SM system, with predicted grain yield within 10% of observations (Sinclair and Amir, 1996). Green and dry straw mulches conserved 15 and 13.7% more water than the no mulch treatment in the top 500 mm of the soil profile. Compared with the no mulch condition, grain yield was increased by 47, 43 and 16% respectively under green, straw and soil dust mulching. Besides vegetative mulches, soil dust mulch also increased the crop water use efficiency (Moitra *et al*., 1996).

Mulching decreased maximum soil temperature and kept the surface layers wetter, resulting in better root growth (Gajri *et al*., 1994). Mulching increased stored moisture in the profile at wheat seedling by 31-88 mm. Over the years, mulching increased wheat yield by 11-515 kg ha^{-1}. Wheat yield response to mulching was related to rainfall patterns during the growing season. Significant response to mulching was obtained only in years when rainfall during the vegetative phase of crop growth was low (Sandhu *et al.*, 1992). Application of mulches significantly increased pods/plants, seeds/pod, test weight and seed yield and maintained better soil moisture during crop growth in semi-arid lateritic regions sub-tropical India. Mulches proved useful to conserve more moisture in soil profile and thereby increased crop water use efficiency. Straw mulch was found to be superior to leaf mulch (Zaman and Mallick, 1991).

<u>(iii) The advantage of mulch</u>

a) <u>Mulch significantly increases crop yield</u>

Mulch affects many soil properties, which directly influence crop yield. Mulches proved useful for conserving more moisture in soil profiles and thereby increased crop water use efficiency (Zaman and Mallick 1991). Mandal and Mahapatra (1990) obtained similar results and found the yield from straw mulch treatments was 11 to 17% higher than no mulch. Soybean grain yield was significantly higher, at 62.5% of the control. Moitra *et al*. (1996) compared the effects of different mulching materials on a sandy loam (Typical Ochraqualf) soil in eastern India. They found that, compared with the no mulch treatment, grain yield increased by 47, 43 and 16%, respectively, under green, straw and soil dust mulching. Therefore, the increased crop yield on mulched areas is clearly acknowledged by researchers and farmers.

b) Mulch beneficial on Nutrition

Mulches may affect soil nutrient levels and consequently alter crop growth, grain yield and quality (Walsh, 1996). Mulched alley cropping systems provided the lowest annual soil and nutrient losses and gave similar maize yields. Applied straw mulch in irrigation furrows can substantially reduce soil erosion and N and P losses to surface water runoff (Comia, *et al.*, 1994). Shock *et al*. (1997) studied soil erosion and nutrient losses in irrigation furrows under straw mulching. After 17 irrigations, straw reduced runoff volume by 43%. Cumulative sediment lost after 17 irrigations was 17 t ha^{-1} for mulched and 333 t ha^{-1} for unmulched furrows. Straw also reduced NO_3^- and NH_4^+ losses in runoff solution and sediments. Total N losses during the first six irrigations were 33 kg ha^{-1} from mulched and 230 kg ha^{-1} from unmulched furrows. Straw effects on N loss were only through changes in the runoff volume and sediment loss. In contrast, as fertilizer P increased, PO_4 concentrations in runoff solution and sediments also increased. Averaged across the first six irrigations, straw mulch reduced PO_4 losses in the runoff solution by 59, 61, and 72%, for the 0, 50, and 200 kg P ha^{-1} treatments, respectively. Straw reduced PO_4 losses in the sediment 15-, 11-, and 15-fold for the 0, 50, and 200 kg P ha^{-1} treatments, respectively. Averaged across P fertiliser rates, total P lost after six irrigations was 18 kg ha^{-1} from mulched and 215 kg ha^{-1} from unmulched furrows. Straw mulch decreased erosion of nutrients and surface soil and soil maintained at a suitable soil condition. Furthermore, the decaying of mulching material also could increase soil nutrition and improve the soil structure.

c) Mulch help soil form merit structure

The effect of mulch on soil structure was been documented in many studies. Comia and Paningbatan (1994) found that after a three year trial, saturated hydraulic conductivity and air permeability during the pod development stage of the mung bean crop in mulch were at least twice that in unmulched plots in both the 0-5 and 7-12 cm soil depths. In the 0-5 cm layer, soil bulk density was lower and total porosity and the volume of pores with equivalent diameter >30 μm were significantly greater in mulched than in unmulched plots, The opposite was true for the pore volume within the 10-30 μm and <0.2 μm diameter ranges. Compared with different straw materials, wheat straw was particularly effective, because it produced a large number of individual mulch elements, resulting in a more uniform pattern of incorporation, good contact between the mulch and the soil and sufficient material on the surface to form miniature dams, behind which water ponds and protects the soil against crusting. In contrast, maize stalks perform badly, because their large size means that the surface is sparsely covered, contact with the soil is poor and the individual elements are easily washed out and transported downslope (Morgan, 1995).

d) Mulch retains high soil moisture

Many research results have reported the effects of mulching on soil moisture. Mbagwu (1991) investigated the effects of different tillage methods and mulching on soil physical properties on a sandy clay loam in Tanzania. Soil moisture reserves in the 0-15 cm layer were highest under mulch, compared with bare treatments. Soil moisture under black polythene was higher than other mulch treatments, due to vigorous crop growth in the other treatments, which presumably depleted moisture reserves more rapidly. Crops grown under rainfed conditions are prone to water stress, owing to rapid loss of soil moisture and development of mechanical impedence to root growth (Rathore *et al*., 1998). Mulch could increase water consumption, crop water use efficiency and gain yield (Zaman *et al*., 1995).

Yunusa *et al.* (1994) indicated the importance of evaluating mulching of winter crops in terms of crop yield in the subsequent growing season, as well as in the current season. Mulched treatments had more available moisture (30 mm), mostly as a result of less water use during cropping in the previous growing season, than the unmulched treatment. Mulching may be used to restrain both transpiration and soil evaporation early in the season to increase the availability of moisture during grain filling. Mulching during the previous growing season had little effect on soil moisture during the summer fallow period.

e) Mulch reduces surface runoff

Kiepe (1996) showed that the control plot sustained an average annual water loss over three years of 31 mm of runoff and a soil loss of 19 t ha^{-1} in semi-arid Kenya. The best treatment (hedgerows with mulch) reduced losses to 13 and 2% of the control. Hedgerows without mulch reduced losses respectively to 23 and 7%, while mulch without hedgerows reduced losses to 41 and 17%. Kukal and Khera (1993) showed that the application of 4 t ha^{-1} of mulch decreased runoff by 57.6%, soil loss by 71.7% and nutrient loss by 60% and increased maize yield in India. When used in vineyards in the Beaujolais region of France, a permanent grass cover, managed by mowing, reduced erosion to <7 % of that in vineyards with bare soil and did not compete with the vines for moisture, despite the hot dry summer period (Morgan, 1995). It is suggested that increased infiltration, promoted by the grass, limited water loss by runoff during storms thus helped to counterbalance any potential water deficit (Gril, *et al.*, 1989). In the Mosel Valley, Germany, grass reduced available water in the top 40 cm of soil in the summer, when rainfalls were about average, but improved the moisture status during dry summers, with no significant difference in yield, compared with maintaining a bare tilled soil under vines (Leihner *et al*., 1996).

From the above discussion, it appears that the effect of mulching, particularly using natural mulch materials, is beneficial for soil conservation, as demonstrated in many studies. Mulch intercepts and dissipates raindrop energy, therefore providing very efficient protection to the soil. Runoff is also decreased, due to a reduction in surface crusting and increased infiltration. The effect of mulching on the soil moisture and temperature regime is dependent on several factors. Firstly, the climate will determine whether mulch application will accentuate or impede plant growth. This will also depend on whether the mulch material is artificial or natural, with the former tending to increase and the latter tending to decrease soil temperatures. Secondly, the timing of the application is important. For example, in temperate areas, where straw mulching can depress crop growth, a later application is often advocated to avoid sub-optimal temperatures during the critical early growth stage. Conversely, in tropical climates, it is likely that a timely application of straw at planting is required, to avoid detrimental effects to seedling growth due to extreme soil temperatures. However, although effects of mulch applications may be observed in crop growth, these are not necessarily mirrored in final grain yield results. There is also a close relationship between the effects of mulch on soil temperature and moisture, although in many cases, it is not clear which of the two is the more important in terms of crop growth and yield. Further examples of the effects of mulching on soil moisture, soil temperature and seasonal crop growth can be found in Mbagwu (1991), Suwardjo and Abujamin (1993) and Gajri *et al.,* (1994).

Summarising the factors that limit maize growth and development, there are some factors difficult to change, such as climate, while many factors can be improved by using sustainable agricultural technology. Compared with the situation of Yunnan, sustainable system technology should be adopted according to local conditions. Under the monsoon climate, Yunnan often suffers early spring drought, which make it very difficult to germinate even maize seeds. An even seedling vigour is the basis of the proper maize density. The early irrigation supply should be very beneficial for obtaining high yields. Secondly, how to maintain the limited nutrient top soil is the main task of sustainable agriculture. Cultivating steep land causes erosion, especially during a wet rainy season. Therefore, it is appropriate to adopt proper mulching methods during the growth season. Thirdly, traditional cultivation methods need to be improved. For a long time, all cultivation and planting were mostly downslope, which is an easy operation for farms. Furthermore, the straw was used as fuel, which reduced availability.

1.7 Project Background and Main Aims

1.7.1 Project Background

Collaborative studies between Yunnan Agricultural University and The University of Wolverhampton have been in progress since 1990. These studies are investigating agricultural development in Yunnan Province, China. Indiscriminate agricultural intensification will accelerate soil degradation of a vital natural resource. Rapid industrialisation and urbanisation, coupled to continuing demands for increased food production, will put further pressure on land use and force greater use of these fragile areas. More effective soil conservation is therefore essential for sustainable increases in productivity on hill slopes in China. Therefore, the joint British-Chinese team has been investigating techniques to improve agricultural development and sustainability in Yunnan, using a variety of approaches and field sites. Specific themes include exploring ways of increasing crop productivity and improving the reliability of production, while enhancing or maintaining soil conservation.

1.7.2 Aim of the Project

The aim of this project is to implement and evaluate agronomic measures designed to improve the productivity of maize and maintain or improve soil conservation, using plots formed from cultivated areas in Wang Jia catchment.

It is part of a larger programme to develop more productive and sustainable cropping systems, linked to the assessment of the environmental, biological and socio-economic impacts of these systems. This includes the development of a land management plan for the catchment, to produce a model for future dissemination and training. Wang Jia was selected as a representative highland catchment in south-west China.

This Ph.D. project forms part of a larger on-going programme which aims to develop and evaluate wider-ranging land management strategies at the catchment level. Part of this programme covers the installation of an irrigation scheme for use in the catchment and the present project includes a comparison of results from two areas, one with and one without irrigation.

Chapter 2 Materials and Methodology

Details of the experimental area in which the research was conducted will be given in this Chapter, together with a description of all field and laboratory methods used. All fieldwork was carried out in Kelang, Xundian County, Yunnan Province, China, from 1998 to 1999. Laboratory analyses of soils were conducted in both Yunnan Agricultural University and The University of Wolverhampton in 2000.

2.1 Site Description

2.1.1 Site selection

Yunnan is a mountainous province belonging to the southern parts of the Tibet Plateau. It is divided into two parts by the Yuanjiang Valley and the valleys of the Yunling Mountains. Its eastern part is Yunnan Plateau, which belongs to Yunnan-Guizhou Plateau, consisting of mid-Yunnan and the east Yunnan Plateau. With a mean height of 2,000 metres above sea level, the undulating terrain generally rises and falls gently. Mountains, hills and many kinds of karst topography are found in Yunnan. In the western part, the Hengduan Mountains, longitudinal valleys are dangerously steep with large relative surmounts. The height of the southern part is from 1,500-2,200 m, compared with 3,000-4,000 m in the north. In the south-western border areas, the elevation is lower, with open river valleys, heights of 800-1,000 m and some individual places are <500 m. These areas are important, tropical and subtropical regions of Yunnan. The terrain of the Province slopes from north-west to south-east, which makes the rivers flow to the east, to the south and to the south-east.

There are major differences between the elevations in Yunnan. The highest point is Kagebo Peak on the snow-covered Meli Mountain of the Nushan Mountains in Deqin County, lying on the border of Yunnan and Tibet, with an elevation of 6,740 m. The lowest is on the confluence of the Nanxi River and the Yuanjiang Rivers in Hekou County, located on the border of Yunnan and Vietnam, with a height of 76.4 m. The straight distance between these two points is 900 km, with a height difference of >6,000 m. The mountain areas are tectonically active and are thus prone to earthquakes, causing landslides, debris avalanches and mudflows (Hao Weiren *et al.*, 1990; Fullen *et al*., 1996). The topographical changes within the Province have resulted in great species richness in natural vegetation, covering tropical rainforest, subtropical broadleaf forest, montane conifer forest, alpine meadow and Savanna. However, because of long and recently dense, human occupation, only ~24.6% of the Province is now covered by natural vegetation. In the early 1950s, the coverage of natural forest in Xishuangbanna was >60%, but after the late 1950s, the forest area was reduced markedly, mainly because of soaring population, indiscriminate reclamation and deforestation (Shi Kunshan, 1999).

The variation in rainfall intensity and distribution has important implications for agricultural operations, which rely on the onset of the rainy season. As a low latitude plateau, Yunnan has a special geographical position, marked by diverse topographical features. It has a low-latitude mountain monsoonal climate, affected by the dry monsoon from the continent in winter and the wet monsoon from the ocean in summer. There are seven types of climates in Yunnan. The north tropical climate, the south subtropical climate, the middle subtropical climate, the north subtropical climate, the south wet climate, the middle temperate climate and the highland climate (Chen Yongsheng, 1990). The climate in Yunnan is characterised by distinctive features which include: (a) marked regional differences and vertical changes; (b) slight variation in annual temperature changes with minimum and maximum annual temperatures of 22.1 and 9.1^{0}C, respectively, but in contrast to dramatic temperature diurnal changes; (c) adequate rainfall, but the distribution is unequal, with mean annual precipitation ranging between 600-1700 mm and most rainfall concentrated in May to September; (d) marked differences in air and soil moisture between the dry and wet seasons.

A variety of crops is grown in Yunnan, due to the wide-ranging climatic conditions. The predominant agricultural areas tend to lie in ‘intermountain basins’ (Thomas, 1992). Rice, maize and wheat are the main food crops, although sugar cane, tea, rubber and tobacco are also important for the typically agrarian-based economy. Maize occupies 23% of the total cropping area and is often grown on infertile, badly eroded steep slopes without irrigation. The planting area of maize in 1995 was 1.0 million hectares, with a yield of 3.4 t ha^{-1} (Yunnan Provincial Government 1996).

2.1.2 Experimental Site Selection

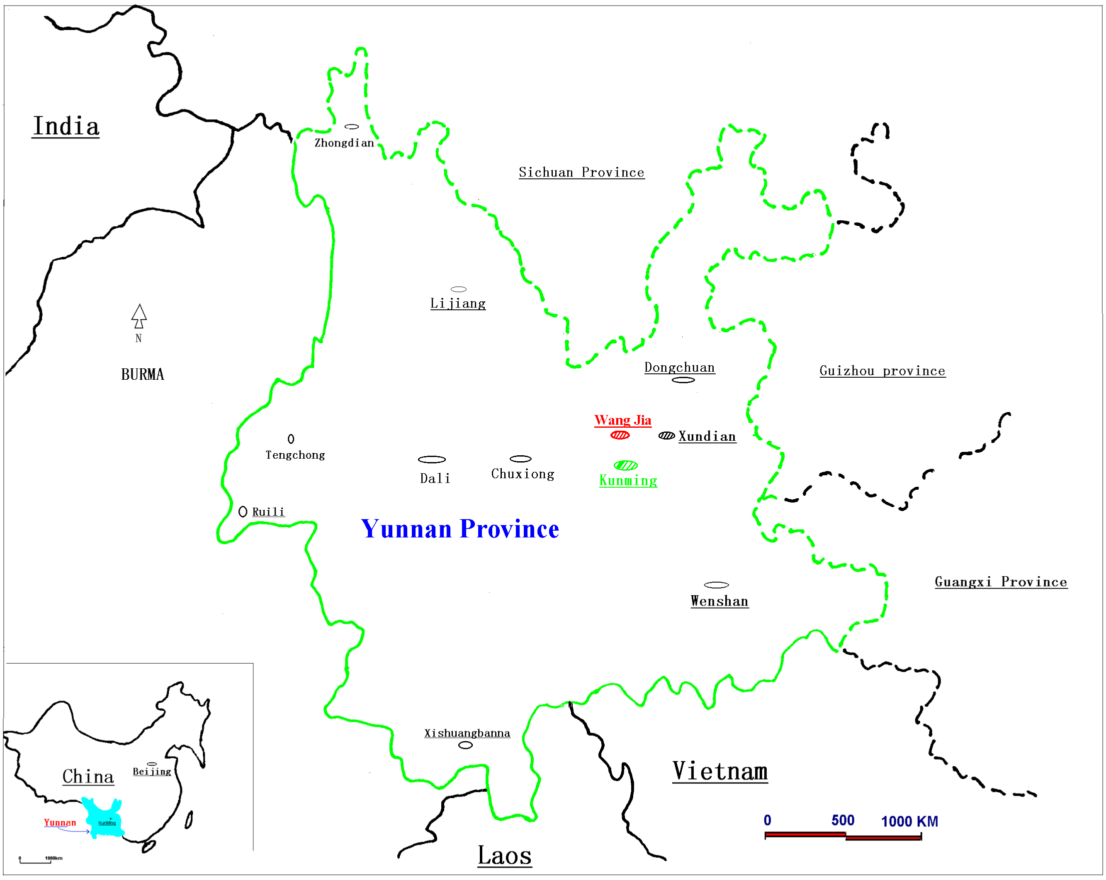
To make the experimental results applicable to a large scale in the hilly lands of Yunnan and similar areas in South-East Asia, several locations were investigated. During site selection for the EU Project (This Project is funded by The European Union (DGXII) under Contract Number ERBIC18 CT98 0326), some particular requirements were identified: firstly, a catchment which was directly associated with a village and cultivated by farmers from the village, secondly, a catchment where steep slopes were cultivated, such that soil erosion from cultivation practise was a potential problem, thirdly, a catchment where the co-operation and agreement of farmers and local government officials were possible. The cultivation practise would have to be changed to evaluate their productivity and economic returns. It was recognised from the outset that effects on soil erosion could only be monitored indirectly. The team from Yunnan Agricultural University and the University of Wolverhampton studied different potential sites, including Dongchuan (Chen Xunqian, 1989), Huizi and Xundian County. The Wang Jia Catchment site was chosen, adjacent to Kelang village in Kedu Township, Xundian County, Yunnan Province. The local topography is representative of ~85% of the upland of Yunnan. Therefore, it is hoped that research results will be beneficial to the uplands of Yunnan and similar areas of South-East Asia. The research of ‘Development of Sustainable Crop Production Systems on Hill Slopes in Yunnan Province, P.R. China’ is located in the EU Project area.

2.1.3 The General Information of Wang Jia Catchment at Kelang Village, Kedu Township

The experimental plots were located in Wang Jia Catchment above the village of Kelang, Kedu Township. The population of Kedu Township is predominately Hui Nationality (one of 26 nationalities in Yunnan), with a population of 36,000 people. There is a total crop area of 2300 hectares, of which 1500 hectares are hilly fields, which occupy 65% of the total cropland in Kedu. The main income of this area comes from crops, such as rice, maize and potatoes and cash crops, such as tobacco. The total grain yield was 11,000 tonnes, of which the summer crop was 7,600 tonnes and winter crop 3,400 tonnes (Kedu Yearbook, 1999). The mean per capita crop grain at Kedu Township in 1998 was 306 kg year^{-1}. The gross economic income was 72.6

million Yuan (£5.6 million, £1 = 13 Yuan) and the net economic income was 25.5 million Yuan (£1.9 million). Total income for farmers is very low, with a net income of 725 Yuan (£55)/year per person (Annual Statistics of Kedu Township, 1998). Kelang is ~70 kilometres north-east of Kunming City and is situated at N25^{0}28’18.8’’, E 102^{0}53’06’’, with an elevation of 2013 m (Fig. 2.1).

Fig. 2.1 The location of the Wang Jia Experimental Site



Because of the abundant iron oxide (Fe_20_3) content in soil (Zhao and Shi, 1986; Xu *et al.*, 1986), the soil is typical Ultisol soil (red earth soil). As there were no meteorological data at Wang Jia Catchment, all initial meteorological data came from Kedu weather station, 10 km from the experimental site. The weather generally belongs to a typical monsoonal climate. Generally, annual rainfall was 1000-1030 mm (Kedu weather station records), which was mainly concentrated in June-September (85% of annual rainfall). The rainy season usually begins in May and finishes at the end of October. It belongs to a temperate climatic zone, with four very different seasons per year. Mean air temperature follows a similar pattern to rainfall, peaking at around June/July. The mean annual temperature is ~16 ^{0}C (Kedu township weather station). A meteorological station was constructed at Kelang Village to support the experimental programme (Chapter 3).

There were 809 families, with a total of 3429 people in 1998. Total cultivated area for Kelang village is 162 ha in which the flat fields occupy 33 ha (20.4%). Sloping land is 129 ha and occupies 79.6% of the total cultivated land. The total crop grain yield was 860 tonnes, and the mean crop per capita was 246.23 kg year^{-1}. Mean net income per person was 1260 Yuan (£97) year^{-1} (Kedu Township Yearbook, 1999).

Wang Jia Catchment is a typical watershed with cultivation in the middle of the catchment and shrubs on upper sections. The relative relief of the whole catchment is 460 m, from the bottom of Kelang village to the summit (Vinck, 1999). There is a small stream flowing in the gully, which has a high discharge during the rainy season. Because of the limited transportation and poor agricultural techniques, the crops, mainly maize, are planted once during the rainy season. Most of fields were left as fallow and bare fields during winter, due to the lack of water. Sometimes, the farmers plant peas on upland fields, after the autumn harvest. Planting can take advantage of the moderate autumn rainfall, but the yield is very low (100-150 kg ha^{-1}).

2.2 Experimental Design

Plot areas were identified and marked out on the west facing slope of Wang Jia Catchment, as 3 x 5 randomised blocks (Plate 2.1), with five treatments in each block. The slope angles were measured using an Abney level. Each plot had a slightly different slope angle, as shown in Fig. 2.3, but all plots were in the range 13-19.2 degrees.

Plate 2.1 **The location of the experimental site in Wang Jia Catchment, showing arrangement of plots on the west-facing slope**

Treatments were allocated randomly to plots within each block, as shown in Fig. 2.2. The distance between two nearby plots was >1 m, to minimise edge effects. The area of each plot was 3x10 m. Larger plots could not be established, because of varations in slope and surface features. The maize cultivar cv. *Huidan No.4,* which is a widely used species in upland Yunnan Province, was chosen for the experiment in the 1998 and 1999 seasons. The treatments were selected according to the reviewing of recent year's experiments and trying to adopt simple methods, which made the results acceptable to the farmer and extended by government easily in the future. Five separate cropping practises were used in the experiment. The cultivation techniques were as follows:

Treatment I: Traditional + Downslope planting (**T+D**).

Treatment II: Traditional + Contour planting (**T+C**).

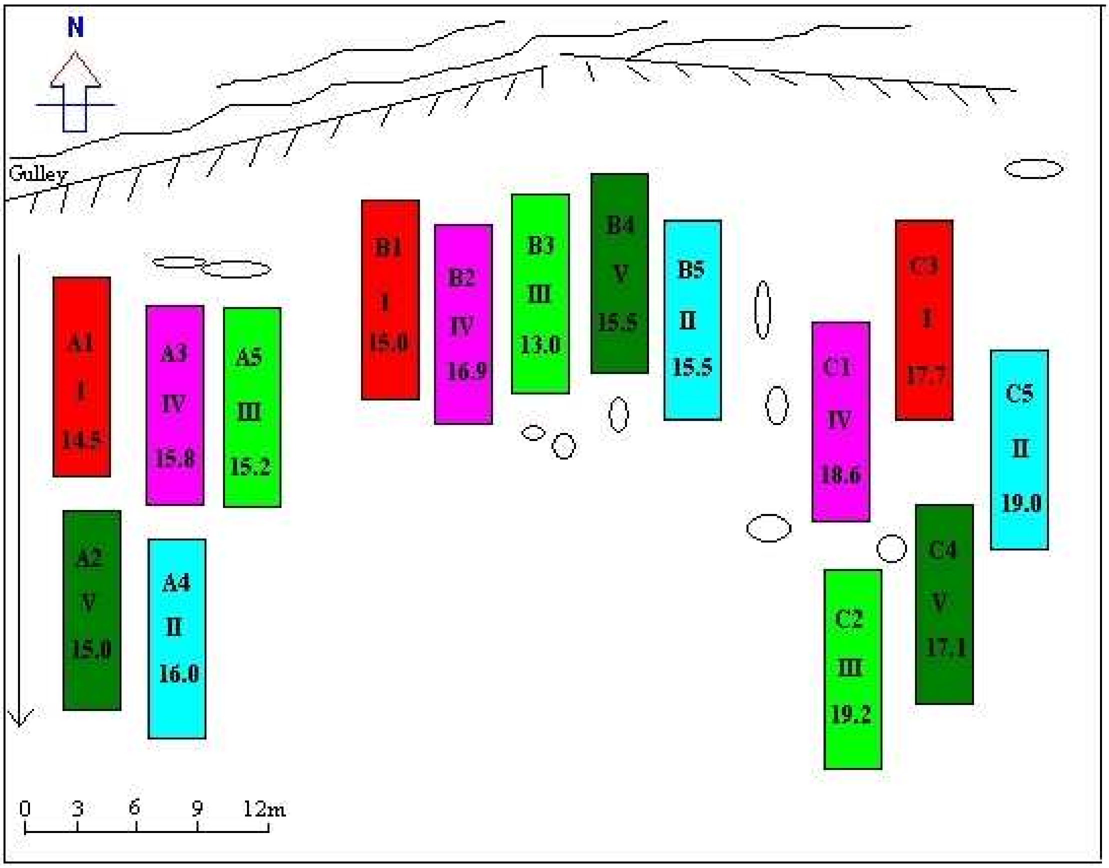
Treatment III: Traditional + Contour + Straw mulch (**T+C+St**).

Treatment IV: Minimum tillage + Contour + Straw mulch (**M+C+St**).

Treatment V: Traditional + Contour + Polythene (**T+C+P**).

The different cultivation practises only refer to the wet (or summer) season crop of maize, but the plots were also used to grow wheat in the dry (winter) season, when the same cultivations were used for all plots.

Fig. 2.2 Site plan in Wang Jia Catchment showing the arrangement of the plots into three blocks (A, B and C) with five treatment plots (I, II, III, IV and V) in each block under different slope angles (13.0-19.2 degrees).



2.3 Cropping System and Cultivation Methods

2.3.1 Wet (or summer) Season Cultivation for Planting Maize

The important aspects of the experimental treatments were the different tillage cultivation and planting methods. Cultivation methods followed those used by local farmers for maize production. Initially, the land was prepared by hoeing by hand, working along the contour for contour cultivated plots and down slope for downslope plots (Plate 2.2). Stubble and roots from the preceding wheat crop were removed during this process. Some standards were made for the depth, direction and width of ploughing. For the traditional tillage plots, the field was ploughed to a depth of 20 cm.

For the minimum tillage treatments, only a 20x20x20 cm^3 pit was dug during sowing. The same maize variety was sown in all plots on 20 May 1998 and 17 May 1999, respectively. Planting density was 60,660 plants ha^{-1}. The distributions of the contour planting and downslope planting are shown in Figs. 2.3 and 2.4.

Plate 2.2 Conventional tillage using the hoe for cultivation treatment at Wang Jia Experimental Site before planting

2.3.2 Dry season cultivation for planting wheat

The field used for the experiment used to be bare, or planted to peas during winter. The experimental site, as it faced south-west, received too much sunlight and was thus too dry to grow winter crops. During winter, there were often force 4-5 (Beaufort Scale) south-westerly winds, which desiccated the soil. How to resolve the problem of winter water supply is a key issue for winter cropping. In order to supply enough water for the winter, some water ponds were built during the implementation of the EU Project, to accumulate stream water and collect rainfall during the rainy season and meet the needs at critical times of crop growth, such as early spring and winter. A wheat cultivar, *Yuanmai No.40* was used for the experiment. This wheat cultivar, which has good resistance to dry weather, was selected by Yunnan Agricultural University. The wheat was planted immediately after maize harvest, in order to use available residual soil moisture. The field was not dug until planting. The field was cultivated, using standard wheat planting techniques (Plate 2.3). The wheat was planted using the contour method.

Plate 2.3 Wheat planting along the contour at Wang Jia Experimental Site in October 1998

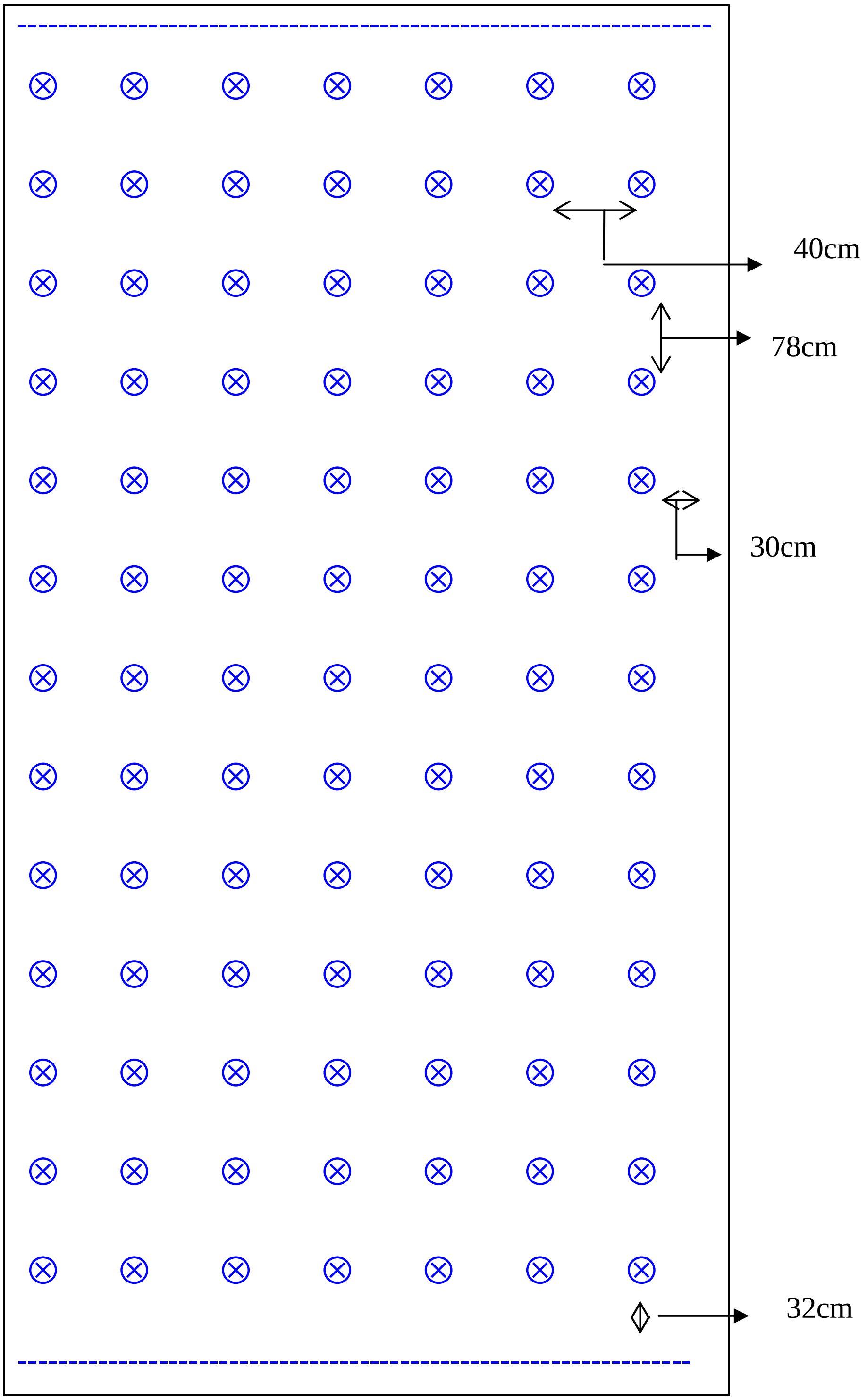
2.3.3 Maize Planting

Maize was planted when the rainy season started. The field was ploughed by hand before maize planting for all the treatments which required ploughing. For the experiment, the maize was planted on 23 May 1998 and 17 May 1999. Pits for planting the maize were 40 by 78 cm, dug 15 x 15 x 15 cm deep to give a density of 3.03 pits m^{-2}, 6.06 plants m^{-2} (two plants per pit) on every plot. The planting pattern of maize for downslope and contour treatments is shown in Figs. 2.3 and 2.4.

Six maize seeds were sown in each pit to ensure the survival of at least two seedlings, manure was then placed on top of the seeds. In 1998, no irrigated water was used after planting, while in 1999, ~5 litres of water were placed in each pit, as there had been little rainfall at the time of planting, after the irrigation system had been established. Urea and superphosphate were sprinkled around the inside of the pit, which was then covered over with soil.

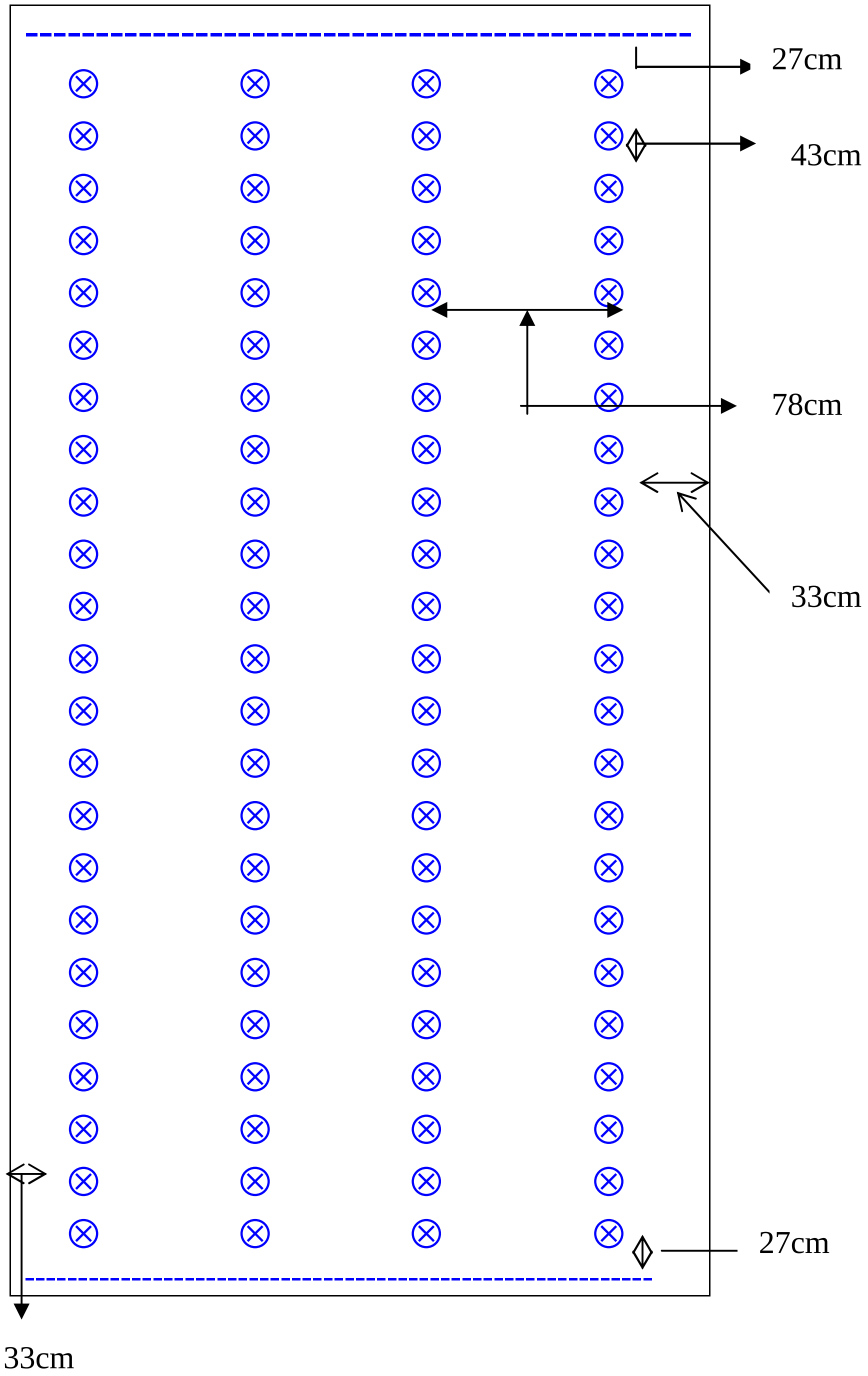
The contour planting method used 15 x 15 x 15 cm planting pits. A total of 91 pits were planted, with row distances of 78 cm within 13 rows and 40 cm within 7 pits. There were 32 cm at the top and bottom and 30 cm on each side. There were 182 plants with 2 plants in each pit.

Fig. 2.3 The design of the contour treatment for the experiment



For the downslope, planting was carried out using traditional tillage and with 15 x 15 x 15 cm planting pits. There were 92 pits with 23 rows. The distance between each row was 78 cm and 43 cm between pits. There were 27 cm at the top and bottom. There were four pits at same horizontal direction. There was 33 cm at both sides and 2 plants per pit were maintained (2 pits just maintain 1 plant) with 182 plants in a plot.

Fig. 2.4 The design of the Downslope treatment for the experiment



Every seed pit received manure application at 0.5 kg. A base dressing of urea nitrogen was applied at a rate of 7.7 g per seed pit and one dressing of superphosphate ($Ca(H_2PO_4)$) at a rate of 10 g per seed pit. Each pit was irrigated with 1-1.5 litres of water at seeding, to assist germination. A further two dressings of urea nitrogen were applied approximately 4 weeks later, with 6 g pit^{-1}, and at 8 weeks, with 10 g pit^{-1} after seeding. All tillage operations were carried out by hand. Weeding was normally conducted each month, though more frequently when required. Problems with cut worms and corn borers were remedied using the 0.5% density of pesticide *Dishasi* (Decamethrin) at 300 kg ha^{-1}. Fertiliser and other material applications are shown in Table 2.1.

Table 2.1 Base fertilizers and mulch materials for experiments in 1998 and 1999

Material \ Use Rate	kg ha^{-1}	kg plot^{-1}	g pit^{-1}
Yard Manure	15000	45	495
Super-phosphate	300	0.91	10
Urea (Base)	225	0.675	7.7
Urea (First add.)	180	0.54	6
Urea (Second add.)	300	0.9	10
Wheat Straw	3000	9	-----
Water	31000	92	1000
Polythene	For the appropriate treatments. Polythene used the clear continuing one.		

Two inter-tillage operations were carried out during the whole growing stage. The first was done at the seedling stage, using the hoe to cultivate the surface soil (0-5 cm) to prevent weed growth. The second time was at the earring stage, with the maize root covered with soil. Additional fertiliser was used twice during the growing season. The first was at the seedling inter-tillage time with 180 kg ha^{-1} of urea, and the second was at the ear emergence stage with 300 kg ha^{-1} urea.

In Yunnan Province, pest and disease problems may occur very quickly, because the weather is very variable. However, during the two years' experiments, there were few pests. Corn borer appeared in the straw mulch treatments during the early growing season, but was controlled by spraying with *Dishasi* (Decamethrin).

2.4 Meteorological Measurements

2.4.1 Weather Station Establishment

As discussed, Yunnan has a monsoon climate, typical of the subtropical and tropical plateau zone, with distinctive dry and rainy seasons and drastic changes in climatic conditions. "*There is different climate among ten miles and four different seasons can be found on the same mountain*" (Chen Yongsheng, 1990) is a description of the diverse climate of Yunnan. There are different rainfalls in different areas with different rainfall intensities. The local climatic data used to be collected by the subweather station at the site of the local township. In order to collect accurate basic weather information for the experiment, a weather station was established at Kelang village in 1997, a year before the experiment began. The weather data were recorded daily by a technician from Kelang village, 500 m from the experimental site (Plate 2.4.1).

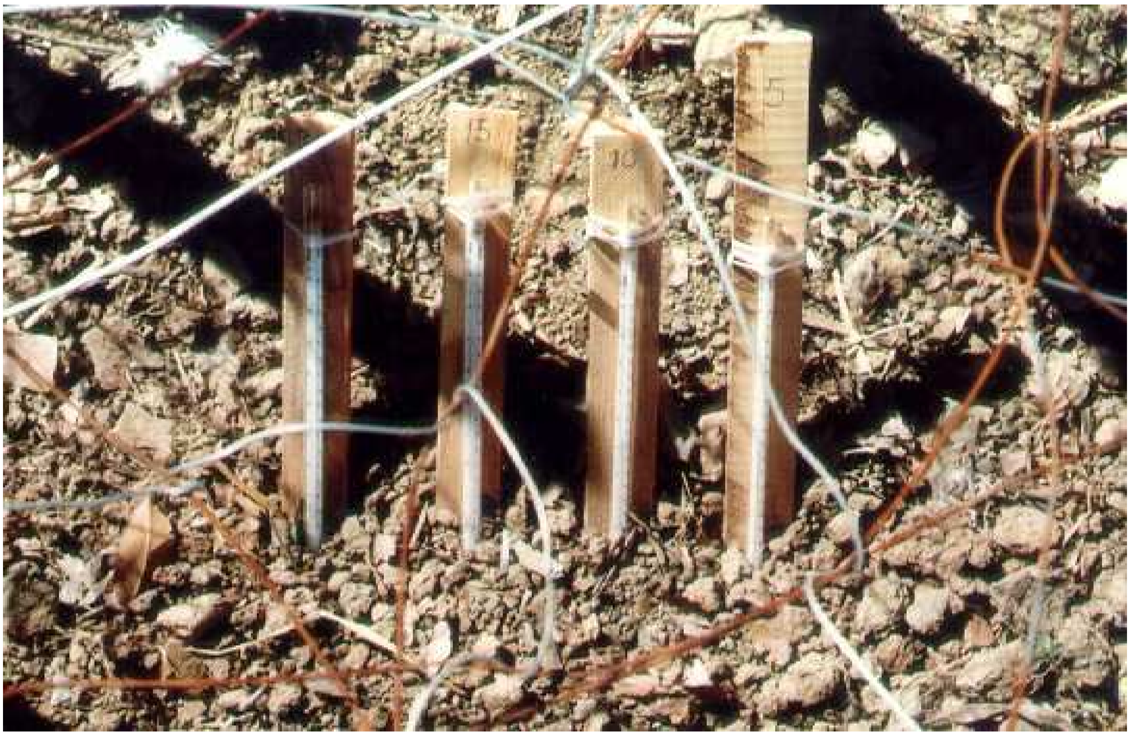
Plate 2.4.1 The Weather Station established at Kelang Village, 500 m from Wang Jia Experimental Site, in 1997

2.4.2 Soil Temperature

Soil temperature influences seed germination in early spring and directly influences the growth of emerging crops by affecting mineralization and water absorption

(Antonopoulos, 1999). Soil temperature was recorded at 0900 every day using soil thermometers inserted permanently into soil at 0, 10, 15 and 20 cm depths (Plate 2.4.2).

Plate 2.4.2 Soil temperature was measured using soil thermometers inserted into soil at different depths (right to left: 5, 10, 15 and 20 cm depth) at Kelang Weather Station in 1997



2.4.3 Rainfall

Rainfall was measured using a tilting syphon rain gauge with a 200 mm diameter collecting area, based on the standard Dines Tilting Syphon gauge used by the U.K. Meteorological Office (Shaw, 1988). The gauge was located on the roof of a farm building, ~500 m from the experimental plots (Plate 2.4.1). The autographic sheet recorded daily information on rainfall intensity, duration and amount. The total amount of rainfall displayed on the autographic sheet was checked against the amount measured in the collector at the base of the instrument. In order to check for accuracy, another manual rain gauge was established at Kelang weather station, for comparison with the tilting syphon gauge and as a temporary replacement in the event of equipment failure.

2.4.4 Air Temperature

The daily air temperature was recorded automatically using a Casella-pattern thermohydrograph and the data were also recorded manually at 0900 each day. The mean annual daily, weekly and monthly temperatures (including mean maximum and minimum temperatures) were calculated from the daily records. In order to gain the data on air humidity, two sets of wet and dry bulb thermometers were established at Kelang weather Station. The records were recorded manually at 0900 every day. Relative humidity was calculated from the two sets of wet and dry bulb thermometers by referring to ‘The Hygrometric Book’ (Yunnan Meteorology Station, 1985).

2.5 Field Measurements

2.5.1 Soil Temperature

Soil temperatures were measured every two weeks after sowing, at five depths (0, 5, 10, 15 and 20 cm) on three occasions (0730-0830, 1330-1430 and 1730-1830 h). Soil temperature readings were taken from the plots using Whatmart Lo-Temp g-Sensor hand-held temperature probes (Plate 2.5.1). The probes were simply pushed into the soil at random locations to different depths and left for two minutes until a stable reading on the digital display was achieved (^{0}C). The reading error was ~±0.1^{0}C. In order to prevent damaging the probe of the thermometer, a graduated steel pole was used to create a hole to the depth where the temperature was to be measured. The measurement point was at the middle of two pits in the same row. Five randomised sites were measured in one treatment. All measurements in the same block of five treatments were completed within one hour. The measurement date was sometimes one to two days later, if it was raining heavily at the time, to avoid errors through excessive water content.

Plate 2.5.1 Whatmart Lo-Temp g-Sensor hand-held temperature probes (Jiangsu Science Facility Factory)

2.5.2 Soil Moisture

There are many different methods of measuring soil moisture, such as soil moisture sensors and soil water potential meters. Because of equipment limitations, soil moisture was measured gravimetrically in soil samples every two weeks after sowing. Samples were taken 20 cm from the stem base of three plants at depths of 0-5, 5-10 and 10-15 cm in top, middle and bottom regions of the plot, using a trowel. The samples (fresh soil) were stored in labelled sealed tins and weighed in the field as soon as possible. The gravimetric water content was determined after drying at 105^0C for 48 hours and re-weighing the sample (Avery and Bascomb, 1974), with the result expressed in grammes (g) moisture per 100 g oven-dry soil, or % moisture by using tin boxes with 100 cm^3 volume. During measurement, 40-50 g of the soil from depths of 0-5, 5-10 and 10-15 cm were collected and put into tin boxes, which were weighed. The tin box was sealed until the fresh weights were measured. Five samples were taken from each plot. If it was raining when the soil moisture required measurement, it was not done until rain stopped, to ensure the soil moisture was representative. After weighing the fresh weights, the soil samples were taken to Yunnan Agricultural University for drying. The soil moisture was calculated from the fresh and dry weight of soil.

$$Soil \quad moisture \ (\%) = \frac{Fresh \quad weight \ (g) - Dry \quad weight \ (g)}{Fresh \quad weight \ (g)} \times 100 \qquad 2\ (1)$$

2.5.3 Soil Penetration

Soil penetrometer resistance is a measure of the ease with which an object can be pushed or driven into the soil, sometimes termed soil strength (Bradford, 1986). The application of such a measure has implications for root growth, crop yield, crusting and soil depth. Soil strength was measured using a hand-held pocket penetrometer, a calibrated spring-loaded device with a protruding piston needle that when pushed into the soil caused the spring to compress. The magnitude of the compression depends on the ease of penetration into the soil. This device was pushed into the soil to a marked depth to give a reading of penetrability in the resistance curve. From the resistance curve, the penetrometer resistence was calculated with the unit of kilograms per square metre (g cm^{-2}) by way of a calibrated spring housed within the casing of the hand held penetrometer (Plate 2.5.2). Five replicate penetrometer readings were taken from each plot on two occasions (beginning and the end of growth) during the growing season.

Plate 2.5.2 Soil resistance measurement facility, Hand-held Penetrometer (NanJing Soil Research Institute)

2.5.4 Soil Bulk Density

Bulk density is a fundamental soil property, which is both itself subject to anthropogenic impact, but is also essential to the interpretation of nutrient budgets (for instance, to perform carbon inventories). Furthermore, it is used to calculate soil porosity, a crucial variable for hydrologists, climate modellers and trace gas modellers (Materechera *et al*., 1997).

Bulk density was measured in all plots using a standard steel cylinder of 5.1 cm depth and 5.0 cm diameter (volume 100 cm^3), using the method described by Landon (1991). The cylinder was hammered into the topsoil with the aid of a driving tool, designed to allow the soil to extend beyond the end of the sampling cylinder, thus avoiding compaction. The cylinder was then carefully excavated and the soil trimmed flush to the ends of the cylinder. Caps were placed on both ends of the cylinder and the whole sample placed in a sealed polythene bag. Each cylinder was weighed as soon as possible after excavation and oven-dried at 105^0C for 48 hours. The core was re-weighed, moisture content percentage calculated and the mass of oven-dry soil expressed relative to cylinder volume. Two depths (0-10, 10-20 cm) were sampled. After two years of experiments with different tillage and planting methods, bulk density changes were measured and evaluated.

2.5.5 Soil Particle Size Distribution

Soil particle size distribution was measured using a Malvern Mastersizer Laser Granulometer. This technique determines the diameter of particles suspended in water, by measuring the diffraction of laser light deflected from the particles as they pass in front of a lens. It is preferable to the pipette method (Avery and Bascomb, 1974), because of its greater rapidity and good reproducibility. With the exception of clays, where the fraction is underestimated, it has been shown to give precise and accurate results in size ranges necessary for environmental studies (Loizeau *et al*., 1994).

Use of the granulometer is restricted to soil particles that have passed through a 2.0 mm sieve, as this excludes platy particles longer than 2.0 mm that could block the plastic tubing in the machine. Therefore, the percentage weight of the 1.0-2.0 mm fraction was recorded and incorporated into the subsequent calculations. Prior to analysis, organic matter was removed from the soil samples by hydrogen peroxide oxidation. This method was preferred to ignition, as high temperatures shatter silt particles giving a misleading result, whereas chemical removal oxidises only the colloidal SOM, which it volatilises, leaving mineral particles behind. For oxidation, 1-2 g of sample was weighed into beakers to which 25 ml of 30% hydrogen peroxide was added. These were heated on a hotplate at 75-80^{0}C in a fume cupboard. Excessive frothing was quenched with small jets of methanol. When vigorous activity subsided, more hydrogen peroxide was added and this process was repeated until frothing stopped. The samples were then left to dry out completely.

Oxidised, dry samples were prepared for introduction to the granulometer (Plate 2.5.3), by being transferred to a plastic 'watchglass.' They were re-wetted by the dropwise addition of 'Calgon' solution (40 g sodium hexametaphosphate per litre distilled water). This disperses particles by breaking down electrostatic bonds between them. They were then gently tamped with a rubber bung to break up aggregates. Each sample was then spread across the 'glass' in a thin uniform paste. Sections of this were introduced to the suspension tank in the granulometer, by gentle washing with a plastic pipette until optimal obscuration (10-15%) of the lens was achieved (C. Booth, pers. comm.). The water in the tank was kept in continuous motion with a stirrer and ultra-sonic energy maintained desegregation. Measurement of each sample was taken over a mean of 6000 sweeps of the detector and three replicates per soil sample were measured. In order to incorporate the full range of sizes, the laser measured particle size on two lenses (4-1000 μm and 0.1-80 μm) and the accompanying software package blended these data to provide a frequency distribution and statistical data for the whole sample across a size range of 0.1-1000 μm. This included cumulative percentages for different diameters, which allowed the percentages of clay, silt and fine sand to be determined. The fine sand percentages were added to the percentages of the 1.0-2.0 mm fraction, previously separated, so that final results could be expressed as percentages of clay (<2 μm), silt (2-60 μm) and sand (60-2000 μm).

Plate 2.5.3 Soil particle size distribution was measured using a Granulometer (Malvern Mastersizer Long-bed X Laser Diffraction (middle)) with MSX17 Sample Presentation Unit (right) and a connected computer, showing the analytical results (left)

2.6 Soil Chemistry

2.6.1 Introduction

Most changes in soil carbon take place in the top 30 cm, but significant amounts of carbon lie at greater depths. Measurements at centres and stations should be 0-30 cm and 30 cm-1 m. Nitrogen is the element most generally limiting primary production in natural and agricultural ecosystems (Eckert, 1989). The capacity of ecosystems to sequester carbon, for instance, is constrained by the maximum ratios of carbon-to-nitrogen (C/N) in living tissues. Several important greenhouse gases (e.g. N_2O and NO_2 and CH_4) are tied to the soil N cycle. As with soil C, most changes occur in the top 30 cm, which should be the sampling standard, but stations and centres should measure to 1 m depth (Eckert, 1989).

Soil P occurs in many forms, which have complex interrelationships. Total soil P is one of the few robust measures. There is no single, standardised method for measuring 'available' P in all soils; there is nevertheless virtue in making this measurement, using an appropriate technique, at stations and centres. Full fractionation of soil P into organic, P secondary, extractable and occluded forms is appropriate at centres and stations, as is assessment of the type and degree of mycorrhizal infection. Characterization of the P-sorbtion relationship is appropriate for soils with high iron oxides (Griffith, 1989).

Soil pH is a fundamental property controlling soil biological and chemical processes, such as biological nitrogen fixation, root growth and the mineralisation of organic matter. It is also an indicator of soil acidification due to acid deposition resulting from industrial processes, or from agricultural activities. There are several standard ways of measuring soil pH, each with advantages under particular circumstances (for example in 1M KCl, 0.01 M $CaCl_2$, saturated paste extract). The proposal is for a single, easily-applied index (Snyder, 1989).

2.6.2 Soil Sampling

Several soil fertility parameters are influenced by erosion and agricultural management techniques. To assess short-term changes in soil nutrient status, several tests were carried out in laboratories both in China and at The University of Wolverhampton, UK. Standard tests on total and available forms of N, P and K were conducted at Yunnan Agricultural University (YAU), following commonly used Chinese laboratory methods, complemented by analysis of pH and organic carbon. Available nitrogen, phosphorus and potassium and total nitrogen determinations were carried out, following procedures outlined by Shi (1988), while the methods for total P and K were based on the 'Handbook of Soil Physiochemical Analyses' published by the Institute of Soil Science of Academia, Sinica (1983). The determination of exchangeable calcium and magnesium were based on procedures given in Allen (1989). A summary of the techniques used for each analysis follows.

2.6.3 Sample Preparation at Wang Jia

For analysis of soils at Yunnan Agricultural University (YAU), two size fractions were obtained, <1.0 and <0.25 mm. The former was used for the determination of available nutrients and the latter for total nutrient concentrations. All analyses at YAU were conducted in duplicate. The air-dry sample was spread out on a large sheet of paper, mixed, halved and quartered. Approximately 300 g were obtained from the sample and the rest returned to the bag. The 300 g sub-sample was then crushed and broken down to remove any soil aggregates and stones and organic material was removed. The sample was passed through a 1.0 mm sieve and the soil remaining on the sieve was broken down further, before sieving once again. This process was repeated two or three times, until most of the sample had been sorted. From the <1.0 mm sample, ~20-25 spatulas of soil were transferred to the 0.25 mm sieve. The <1.0 mm sample remaining was then stored in a labelled bag. The sub-sample on the 0.25 mm sieve was shaken and the soil remaining on the sieve lightly broken down using a pestle and mortar, to break up remaining soil aggregates. This was then sieved and the process repeated several times, until nearly all the sample had passed the 0.25 mm sieve. The <0.25 mm fraction was then stored in a labelled bag.

2.6.4 Available Nitrogen

The analysis of available nitrogen was conducted using a micro-diffusion method with a Conway vessel (Keeney and Nelson, 1982). This method transforms nitrate and hydrolysable nitrate into ammonia using sodium hydroxide and iron sulphate, which are then chemically absorbed by boric acid and measured by titration with sulphuric acid.

Approximately 1.00 g air-dry soil sample (<1.0 mm fraction) was weighed and placed into the outer ring of the Conway vessel, together with 1 g of iron sulphate ($FeS0_4$) and 10 ml of sodium hydroxide (NaOH, 1.8 N). In the inner ring, 2 ml of boric acid were added for the absorption of ammonia evolved during the reaction. A glass lid was carefully placed on the Conway vessel, using an alkaline gum sealant around the edge to prevent ammonia losses. The whole vessel was then placed in a 40^0C ($\pm 1\ ^0$C) oven for 24 hours, which facilitated transformation of the different forms of nitrogen within the sample into ammonia. After removal from the oven, the boric acid (blue-green in colour after alkaline transformation) was titrated with sulphuric acid (H_2S0_4, 0.0101 N). The addition of acid to the mixture returned the boric acid to its original pH and colour, and the volume of acid used was recorded. The available N content (ppm) was then calculated using the following equation:

$$Available\ N\ (ppm) = \frac{(V - V_0) \times N \times 14}{W} \qquad 2(2)$$

Where V = volume of sulphuric acid used to reach end point (ml)

V_0 = volume of sulphuric acid used to titrate the blank (ml)

N = concentration of sulphuric acid (N)

W = weight of soil (g).

For Yunnan red soils, a concentration of <50 ppm is considered low, 50-100 ppm medium, and >100 ppm a relatively high available N concentration (Shi, 1988).

2.6.5 Available Phosphorus

The Olsen method was employed for determining available P, a technique that is widely used and applicable for most soils (Olsen and Sommers, 1982). The extractant was 0.5 M sodium bicarbonate adjusted to pH 8.5 ($NaHCO_3$), which was added to 2.5 g of <1.0 mm soil and shaken for 30 minutes. The anions in the sodium bicarbonate were preferentially adsorbed to the soil, exchanging and releasing phosphate into solution. The solution was filtered and a chemically-complex solution of ammonium molybdate added to a 10 ml aliquot of the filtrate in a volumetric flask, to release carbon dioxide from the samples. Carbon was used in the experiment to absorb organic matter, as this can interfere with colour development, an important consideration in this method. Ascorbic acid was added to the filtrate solution, to ensure adequate sensitivity to the colour spectrophotometer, giving the solution a blue colour. The solution was made up to the 50 ml mark and phosphate concentration measured using a spectrophotometer against a set of known standards between 0 and 0.5 ppm. Available P was then calculated using the following equation:

$$Available\ P\ (ppm) = \frac{Solution\ P\ (ppm) \times Volume\ of\ \ solution\ (ml) \times Dilution}{Air - dry\ soil\ weight\ (g)} \qquad 2(3)$$

Availability indices suggest that a concentration <5 ppm is low, 5-10 ppm is medium and >10 ppm is high (Shi, 1988). These values are similar to those quoted by Landon

(1991), for a P demanding crops such as maize, a concentration <5 ppm is considered deficient, 5-7 ppm moderate and >8 ppm adequate.

2.6.6 Available Potassium

Ammonium acetate (pH 7) was added to the soil sample (<1.0 mm fraction) in the ratio 10:1 (NH_4OA_C:Soil) and the mixture shaken for 30 minutes. Ammonium ions displaced exchangeable potassium, which was then measured directly in the filtered solution with a flame photometer against known standard concentrations (0, 1, 3, 5, 10, 15, 20, 30 and 50 ppm of K). The K concentration was used in the following formula to calculate soil available K:

$$Available\ K\ (ppm) = \frac{Filtrate\ (ppm) \times Volume\ of NH_4OA\ used\ (ml)}{Weight\ of\ \ air - dry\ soil\ used\ (g)} \qquad 2(4)$$

Availability indices suggest that soil available K <60 ppm is low, 60-100 ppm is medium and >100 ppm high (Shi, 1988). Expressed in meq 100 g^{-1} soil, Landon (1991) quoted values of exchangeable potassium with concentrations <0.15 meq 100 g^{-1} soil which would be considered deficient, with a response to fertilisation very likely. A concentration of >0.5 meq 100 g^{-1} soil would be considered rich in available K, with response to fertilisation very unlikely.

2.6.7 Total Nitrogen

The determination of total nitrogen was conducted using the semi-micro Kjeldahl technique. In the Kjeldahl method, organic N in the sample is converted to NH_4^+-N by digestion, using concentrated H_2SO_4 containing substances that promote conversion. The NH_4^+-N is determined from the amount of NH_3 liberated by distillation of the digest with an alkali. The total N content of soils ranges from <0.02% in subsoils to >2.5% in peats, and the topsoil of most cultivated soils contains between 0.06-0.5% total N (Bremner and Mulvaney, 1982).

The samples were treated with sulphuric acid and a catalyst added to transform the organic nitrogen into ammonium sulphate. The catalyst used in the determination (KSO_4:$CuSO_4$:Se in the ratio 100: 10: 1) had two main functions: firstly, to increase the liquid boiling temperature, and secondly to speed up the reaction. After heating the solution for 2 hours to between 360-410^{0}C (to ensure boiling point was reached), the cooled solution was transferred to a 50 ml volumetric flask and made up to the mark with distilled water. A 20 ml aliquot of this solution was then used in the distilling process. Sodium hydroxide (10 N) was added to the aliquot (~20 ml) and the solution heated by steam produced from a central flask for 5-10 minutes. The ammonium sulphate was transformed into ammonia gas, which mixed with the water vapour. Both the ammonia gas and water vapour were then condensed and the ammonia in solution was absorbed by boric acid. The mixture was then back-titrated with sulphuric acid, to find the total nitrogen content of the soil sample, as with the available N determination. The concentration of total nitrogen in the sample was calculated using the following formula:

$$Total\ N\ (\%) = \frac{(V - V_0) \times N \times 0.014 \times 2.5}{Oven - dry\ weight\ of\ soil} \times 100 \qquad 2(5)$$

where V = volume of sulphuric acid used to reach end point (ml)

V_0 = volume of sulphuric acid used to titrate the blank (ml)

N = concentration of sulphuric acid (N)

W = oven-dry weight of soil (g)

2.5 = dilution factor.

2.6.8 Total Phosphorus

Total P analysis of soils requires the conversion of insoluble materials to soluble forms suitable for colourimetric procedures, and the two most widely used methods for extraction are digestion with $HClO_4$ and fusion with $NaCO_3$ (Olsen and Sommers, 1982). The method used here relied on the fusion method, but in a sodium hydroxide/ethanol solution at high temperature (Institute of Soil Science of Academia Sinica, 1983). Approximately 0.25 g of soil (<0.25 mm) was weighed into a silver crucible and 2 g sodium hydroxide and a few drops of ethanol added. The mixture was then heated in a muffle furnace for 15 minutes at 400^{0}C and for a further 15 minutes at 720^{0}C, after which the solution was green in colour. This procedure caused the structure of the soil particles to change and ensured that all minerals became soluble. After heating, water was added to bring the minerals into solution and the mixture was heated on a hot plate at 80^0C for 5-10 minutes, to achieve a liquid sample. This was then transferred to a volumetric flask using hydrochloric acid (to precipitate any silver that had entered the sample from the crucible) and dilute sulphuric acid (to dissolve the sample). Thus, the solution contained the total phosphorus from the soil sample. A 5 ml aliquot of the filtered solution was then transferred to a 50 ml volumetric flask, to which 20 ml of distilled water and a few drops of p-nitrophenol (pH indicator) were added to confine the pH range. Sodium carbonate ($NaCO_3$, 10% v/v) and 5% sulphuric acid were then added to balance solution pH. Ascorbic acid and the ammonium molybdate solution used in the determination of available P were also added to the aliquot and the sample shaken to release carbon dioxide. The colour spectrophotometer was then used to measure P absorption, with standards from 0-1 ppm, as with the determination of available P. Absorbance of each sample was recorded and total phosphorus calculated using the following formula:

$$Total\ P\ (\%) = \frac{Solution\ P\ (ppm) \times Solution\ volume \times Dilution\ (ml)}{Oven-dry\ soil\ weight\ (g) \times 106} \times 100 \qquad 2(6)$$

2.6.9 Total Potassium

The same heated sample used for the determination of total P was used to measure total K. Once the sample had been subject to structural deformation by heating, the solution was filtered and diluted with distilled water. After heating and filtering, a 10 ml aliquot of the filtrate was transferred to a 25 ml volumetric flask and made up to the mark with distilled water. Measurement of total K in the solution was undertaken using the same method as available K, using the flame photometer and a set of standards between 0 and 50 ppm of K. The following formula was then used to calculate total K concentration:

$$Total\ K\ (\%) = \frac{Solution\ conc.\ (ppm) \times Filtrate\ volume \times Dilution\ (ml)}{Oven-dry\ weight\ of\ soil\ (g) \times 10^6} \times 100 \qquad 2(7)$$

2.6.10 Soil pH Value

The pH of the air-dried soils was measured using a Hanna temperature-regulated pH metre, both in distilled water and a calcium chloride solution (Avery and Bascomb, 1974). The ratio of soil:water was 1:2.5 (10 g soil:25 ml water). The solution was stirred, left for 10 minutes, then the calibrated pH electrode inserted into the solution. The pH was recorded after 30 seconds, with duplicate readings on each sample. The pH value in 0.01 M $CaCl_2$ was then determined, with the resultant pH usually ~0.5 units lower than in water. Measurement of pH in a salt solution ($CaC1_2$) attempts to standardise pH conditions further (Rowell, 1994). The difference between the pH in water and that in the salt solution can indicate whether the soil has a net negative, or a net positive, charge.

2.6.11 Soil Organic Matter

Soil organic matter (SOM) was determined using a revised method of the Walkley-Black procedure (Walkley and Black 1934, given in Rowell, 1994). A known volume of potassium dichromate acid solution (40 ml) was added to the soil samples in conical flasks and gently heated for two hours on a hot plate at a temperature of 130^0C to oxidise all organic carbon. The excess dichromate was then determined by titration with ferrous sulphate, using diphenalamine sulphate as an indicator. Organic carbon was calculated using the following formula:

$$Organic\ C\ (mg\ C\ g^{-1}\ air-dry\ soil) = \frac{48 \times (1-\frac{x}{y})}{Air-dry\ soil\ weight\ (g)} \qquad 2(8)$$

The result was expressed relative to the equivalent oven-dry soil weight. Determinations were carried out in triplicate and the mean calculated. The value of organic carbon was converted to SOM, assuming that 58% of organic matter is organic carbon (Rowell, 1994).

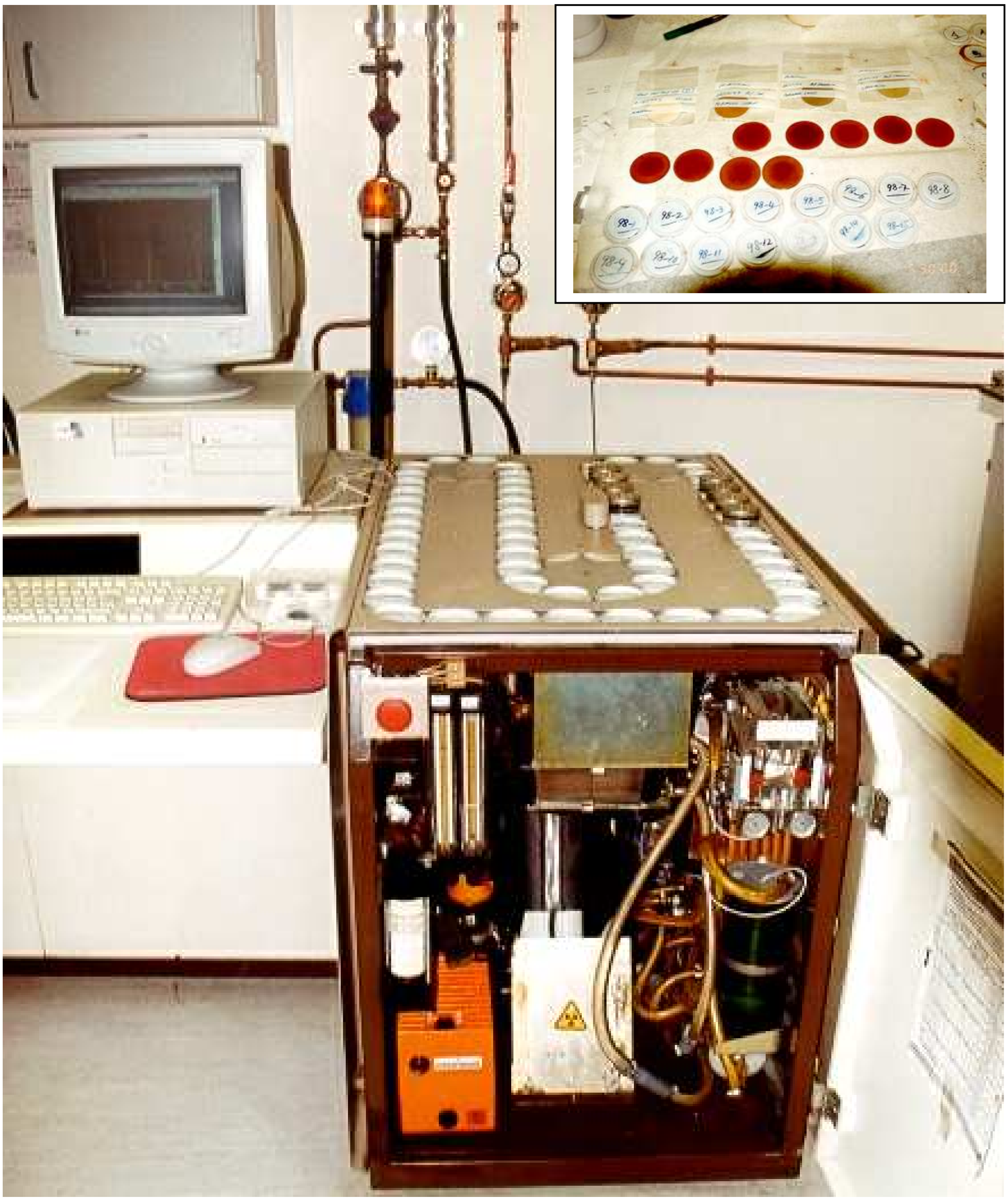
2.6.12 Other Analysed Elements

Beside the main eight parameters (total and available NPK, pH and organic carbon) analysed at Yunnan Agricultural University, other elements (Fe, Cu, Zn, B, Mg, Mn and Ca) were analysed at The University of Wolverhampton, using Wavelength dispersive X-ray Fluorescence Spectrometry (XRF).

XRF is a non-destructive analyses technique, used to identify and determine the concentrations of elements present in soil, powder and liquid samples. XRF is capable of measuring all elements from beryllium to uranium and beyond, at trace levels often below one part per million, and up to 100%, with modern, computer-controlled systems. The analyses procedure includes two parts: firstly, sample preparation. The oven-dry soil sample has the organic component removed at 105^0C overnight, then 375^0C for 16 hours. The soil is milled for about 10 minutes in the milling machine. A total of 8.5 g of the milled sample is added to 1.5 g of Hoerscht wax powder; two glass balls are put into the sample and placed into the mixer for 10 minutes. The sample is removed from the mixer and put into a small plastic dish. It is then put into the gravity press to 15 t cm^{-2}. The press disk is sprayed with hairspray, in order to prevent dust exiting the machine (Plate 2.6.1 above right).

The second step is the XRF analysis. This technique bombards samples with primary X-rays, which make them fluoresce, generating secondary X-ray. These can be analysed using an artificial crystal with known atomic spacing, to determine the wavelengths of secondary X-rays. These are characteristic for elements, related to the energy levels of different electron shells (Plate 2.6.1, centre).

Plate 2.6.1 The elements Fe, Cu, Zn, B, Mg, Mn and Ca were analysed automatically using X-ray Fluorescence Spectrometry (XRF) (Fisons ARL 8410), with the results recorded by a connected computer at The University of Wolverhampton



2.7 Crop Growth, Development and Yield

2.7.1 Plant Sample Selection

After recording germination and then thinning to two plants per pit, eight plants for the further measurement were selected using ‘Z’ type distribution from top to bottom along the plot, avoiding the border plants in case of edge effects. Non-destructive measurements were carried out at intervals during the growing season after fertiliser application, including height, leaf number, leaf area and green leaf area index (GLAI). The same eight plants were used per plot, with non-representative and border plants excluded.

A) Plant height

Plant height was measured every two weeks after thinning the seedlings. The height was measured from the soil surface to the top of the longest leaf. After maize flowering, the height was measured from the ground surface to the top of the flower.

B) Maize leaf number

The leaf number was recorded every two weeks, using fully expended leaves, so the leaf sheath could be seen and recorded.

C) Green Leaf Area Index and Green Leaf Area Duration

The most suitable definition of Green Leaf Area Index (GLAI) is half the total green leaf area (one-sided area for broad leaves) in the plant canopy per unit ground area. GLAI describes a fundamental property of the plant canopy in its interaction with the atmosphere, especially concerning radiation, energy, momentum and gas exchange (Monteith and Unsworth, 1990). Leaf area plays a key role in the absorption of radiation, in the deposition of photosynthates during the diurnal and seasonal cycles, and in the pathways and rates of biogeochemical cycling within the canopy-soil system (Bonan, 1995; Van Cleve, 1983). Various soil-vegetation-atmosphere models and BGC models use LAI (Sellers, 1986; and Bonan, 1993a). Globally, GLAI varies from <1 to >10, but also exhibits significant variation within biomes at regional, landscape and local levels.

Maize leaf growth directly affects the final maize yield. The Green Leaf Area Index can identify the efficiency and economic value of the experimental treatments. Green Leaf Area Index (GLAI) of the maize was measured in all plots at different growth stages. Eight plants were selected as indicative of the general crop within the plot and measured manually. The Green Leaf Area was measured by the maize leaf length and width. From these data, individual leaf areas are calculated by multiplying the length by the width, then multiplying this by a previously calculated factor of 0.75. Total leaf area for each of the number of plants with the plot gives total leaf area. The value of total leaf area was then divided by the area of the plot, to give GLAI (Equation 2 (9)). Where 0.75 is a correction factor provided by the seed manufacturer, which accounts for the shape of the leaf. LAI refers to green leaf area index only, as senescent leaf parts were not measured. Using these data, the Green Leaf Area Duration (GLAD) and mean number of leaves per plant for each treatment were calculated (Plate 2.7.1). If a leaf was half green then only half of the leaf was measured.

Plate 2.7.1 Soil and maize components were measured during the whole crop growth stage at Wang Jia Experimental Site

a) Plant measurement

b) Soil sampling

Green leaf area was measured every two weeks after the first measurement and about seven times during both seasons. Leaf Area Index was calculated by:

$$GLAI = \frac{Leaf\ \ length\ (cm) \times Leaf\ \ width\ (cm) \times 0.75}{Ground\ area\ per\ plant(cm^2)} \qquad 2(9)$$

The Green Leaf Area Duration (GLAD) was calculated by using the GLAI curve during whole growing stages and calculating the total area under the curve by dividing the area into a certain square (adjusting the 100 unit squares to each measurement time) and calculating the 100 squares area (or weight). The total area under the LAI divided by the 100 squares area, then time the days between two time’s measurements give GLAD. All the measured plants were calculated using the Excel Program.

$$GLAD\ (Day) = \frac{Area\ under\ GLAI \times Days\ between\ two\ time's\ measurements}{Area\ of\ 100\ squares} \qquad 2(10)$$

2.7.2 Yield and Biomass Components

After harvesting, the eight recorded plants for measurement during the growing stage were taken to the laboratory at Yunnan Agricultural University for detailed analysis. The measurements included plant height, leaf number, cob number; fresh and dry leaf, stem and cob weight; stem girth (bottom part of stem), cob girth (middle part of cob), cob length, rows of grain, grain every two rows and fresh biomass and yield.

After measurement of the fresh components, samples were put into an oven at 80^0C for 48 hours, to measure the oven-dry matter, including dry leaf, dry cob, dry stem and dry grain weight. The yield of different treatments was calculated, based on these data.

The maize yield of whole plots records was calculated after collecting the sampled plants. The whole cob of each plot was weighed and the mean of 5 cobs were selected to determine air-dry grain yield. The total air-dry grain of the plot is calculated by the dry/fresh rate. The yield may show some variation to the results calculated from the 8 sampled plants, but it is closer to the real field yield.

2.8 Statistical Tests Used for Analysis

Where possible, statistical techniques have been used to analyse the data and to test for significant differences. For analyses of soil data, a grouped regression technique was used to test for significant differences between treatments. By plotting individual parameter results from each plot during the cropping season, a series of regression lines were produced, which were then subject to comparison using grouped regression by using SPSS 8.0 and Minitab12. Where statistical analysis was unsuitable, standard errors of data sets have been included, to demonstrate variance around mean values using Microsoft Excel. Standard regression analyses used Excel. For all treatments and blocks, two-way Analysis Variance (ANOVA) was used to determine the significance of difference and interaction effects. The factor effects between some relative components were determined by combining SPSS 8.0 with Excel 97.

Chapter 3: Experimental Results and Analysis

3.1 Introduction

The results are based on experimental work over two years, with four seasons (two winter seasons planted with wheat and two summer seasons planted with maize) of field-based research and associated laboratory experiments. They have been presented in a sequence, which accords with the aims and measurement procedures set out in Chapter 2.4-2.7. Firstly, analysis of meteorological records of 1997 and 1999 are discussed, including total rainfall, rainfall intensity, soil temperature, air temperature and relative humidity. Chapter 3.2 analyses the meteorological correlations of Wang Jia Catchment (rainfall, temperature, humidity). Chapter 3.3 examines the influence of selected treatments and irrigation on soil physical properties (bulk density, penetrometer resistance, structural stability, soil moisture and temperature). Changes in soil fertility properties, including N, P, K, organic matter, pH, Ca, Mg and particle size distribution, are documented. The development of maize during the summer season and the wheat yield parameters during the winter season from the plots (including measurements of plant height, Green Leaf Area Index, grain yield and other yield parameters) are discussed in Chapter 3.4 and 3.5, effects on wheat yields are discussed in Chapter 3.6, analyses of relationships in Chapter 3.7, cost benefit analyses in Chapter 3.8 and the results are summarised in Chapter 3.9.

3.2 Meteorological Measurements

The monthly statistics for Kelang Meteorological Station are shown in Table 3.2.1. Here some of the data are selected for further discussion.

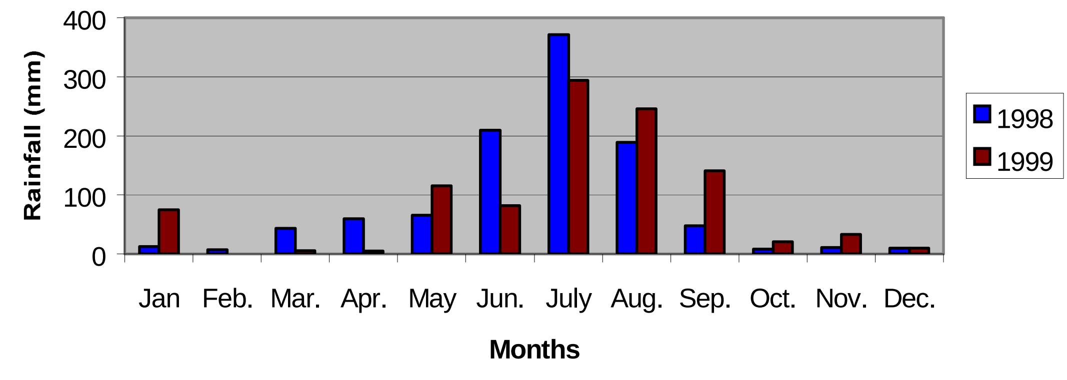
3.2.1 Rainfall

The main limiting factor for crop germination and growth was soil moisture during the early spring in Yunnan Province. Although the total rainfall did not vary greatly, the distribution in individual months was very different from year to year (Yi Minhui, 1997). To enable interpretation of rainfall and crop growth data, detailed rainfall records were collected throughout both crop growing seasons. The monthly distributions of rainfall at Wang Jia Catchment for 1998 and 1999 are presented in Fig. 3.2.1.

Table 3.2.1 The statistics of Kelang Meteorological Station

	Parameters		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1998	Rain (mm)		12.4	6.5	43.1	59.5	65.6	209.4	371	188.8	47.5	7.6	10.9	9.5
	Total Rainfall	1032												
	>15mm/30min (time)		0	0	0	0	1	3	7	2	0	0	0	0
	Highest Temp. (˚C)		16.7	18	22.5	24.3	27.4	25.2	24.4	24.1	24.7	22.2	20.3	16.2
	Lowest Temperature (˚C)		0.9	3.3	6.6	9.2	13.8	17.3	17.7	17	13.1	10.8	5.7	2
	Mean Temp/month		8.8	10.7	14.6	16.8	20.6	21.3	21.1	20.6	18.9	16.5	13.0	9.1
	Mean Temperature (˚C)	16.0												
	Monthly Mean Soil Temperature (˚C)	5 cm	6.1	7.4	11	15.1	20.6	20	20.2	19.9	17.3	15.1	10.2	6.9
		10 cm	6.8	7.9	12.2	15.5	20.6	20.2	20.5	20.2	17.7	15.8	10.8	7.6
		15 cm	7.6	8.8	13.2	16.4	21.3	20.9	21	20.7	18.5	16.5	11.6	8.4
		20 cm	8.2	9.1	14.1	17.1	21.9	21.3	21.3	21	19.2	17.3	12.2	9.1
	Monthly Mean Dry bulb (˚C)		4.7	7	13.2	16	20.3	20.4	20	20	17.2	15.2	10.6	5.4
	Monthly Mean Wet bulb (˚C)		3.4	5.4	9.5	12.2	15.3	17.6	18.7	18.2	15	12.7	9.5	4.5
	Monthly Mean Relative humidity (%)		62	61	59	60	65	77	84	83	82	80	75	74
1999	Rain (mm)		74.7	0.0	5.7	5.0	115.5	81.1	293.8	245.8	141.0	20.4	32.9	9.5
	Total Rainfall	1025												
	>15mm/30min (times)		1	0	0	0	1	0	4	2	1	0	0	0
	High Temperature (˚C)		15.5	21.1	24.3	26.5	23.0	27.3	26.4	25.88	25.1	23.65	18.4	13.1
	Monthly Mean Low Temperature (˚C)		-0.5	2.8	5.6	11.1	13.0	17.2	16.5	15.4	13.7	12.1	5.2	4.0
	Monthly Mean Mean Temperature/month		7.5	11.9	14.9	18.8	18.0	22.2	21.5	20.6	19.4	17.9	11.8	8.5
	Mean Temperature (˚C)	16.1												
	Monthly Mean Soil Temperature (˚C)	5 cm	5.4	8.5	12.4	18.5	17.4	20.9	20.3	19.4	18.0	16.24	10.6	6.7
		10 cm	6.2	9.4	13.2	19.3	17.9	21.0	20.5	19.74	18.3	16.61	11.3	7.4
		15 cm	7.0	10.2	14.1	19.8	18.4	27.6	20.9	20.11	18.5	16.97	11.7	8.1
		20 cm	7.6	10.9	14.9	20.5	19.0	21.5	21.3	20.45	19.0	17.35	12.3	8.7
	Monthly Mean Dry bulb (˚C)		4.4	8.4	13.6	18.4	16.7	21.6	20.2	18.9	17.8	16.5	9.9	7.2
	Monthly Mean Wet bulb (˚C)		3.3	6.3	8.7	13.1	13.9	18.7	18.4	17.5	16.2	14.6	8.9	6.1
	Monthly Mean Relative humidity (%)		67	62	58	61	72	68	85	84	81	80	76	75

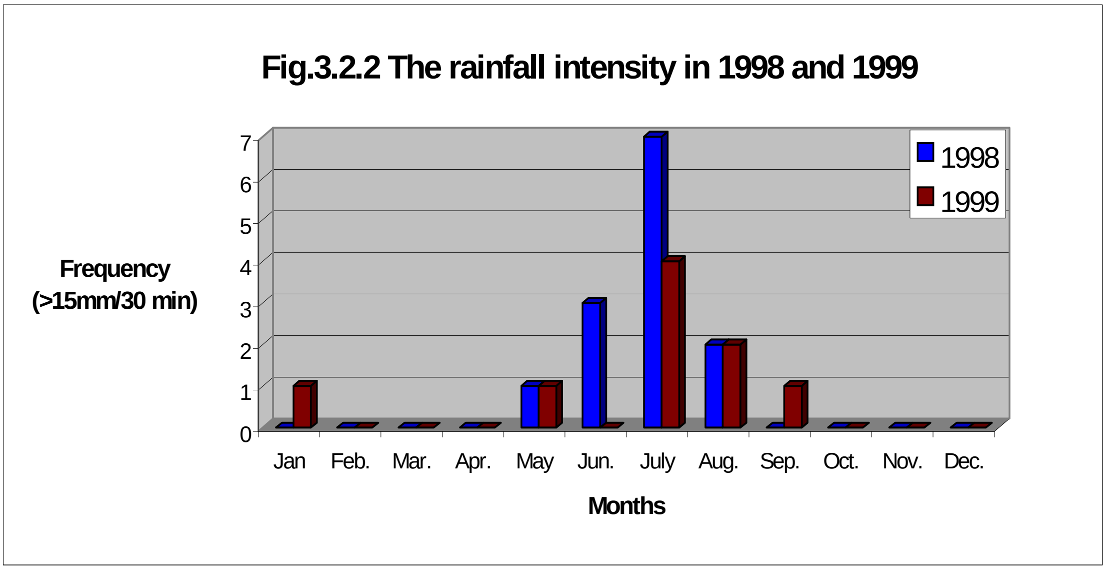
Fig. 3.2.1 The rainfall distribution during the two experimental seasons in 1998 and 1999



Over the two years of research, total precipitation was 1032 and 1025 mm for 1998 and 1999, respectively, with just 7 mm difference in total rainfall between 1998 and 1999. By comparison with the 30-year mean of 1020 mm (Yunnan Meteorological Station, 1995), the rainfall was very close to the mean annual rainfall of Kedu Township, where the experiment is located. However, the distribution of the monthly rainfall was highly variable. Rainfall was mainly concentrated between May to September, with ~85.5% of the total in 1998. In 1999, the onset of rainfall was unusually late, with less rainfall than 1998. This limited germination on all plots, necessitating re-seeding and additional irrigation, to ensure complete establishment. The rainfall in June 1999 was very low with 81.1 mm, 38.7% of the value for the same month in 1998. Less rainfall in June markedly affected early maize growth, discussed later in Chapter 3.4.

3.2.2 Rainfall Intensity

Runoff on steep field is usually caused by isolated storms, when the rainfall intensity is ≥15 mm/30 minutes (Jiang, 1992). These storms occur occasionally in Yunnan, as it is located in the monsoon climatic zone. Therefore, from the rainfall records, the potential for runoff can be generally assessed. The intensity of rainfall was recorded by the autographic rain gauge. Occurrences of intensity >15mm/30min in each month were calculated, with 13 and 10 events in 1998 and 1999, respectively. They were mainly concentrated from May to August, especially in July, when there were 7 and 4 occurrences, accounting for 54% and 44.4% of the total occurrences in 1998 and 1999, respectively (Fig. 3.2.2).



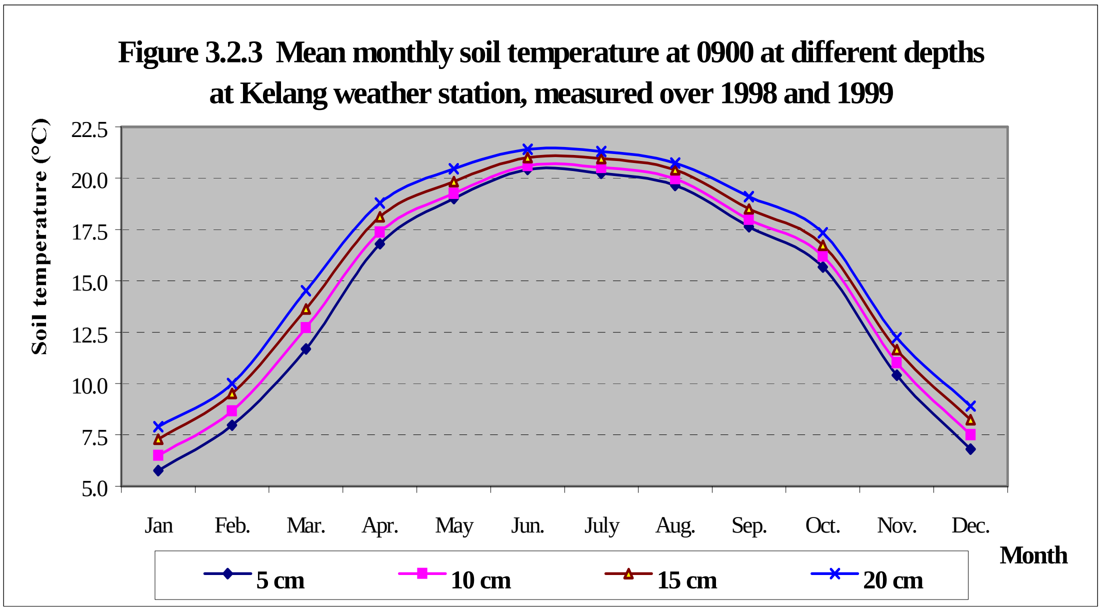
The 13 events in 1998, which totalled 492.5 mm, accounted for 47.7% of the annual rainfall total. The 10 events in 1999, which totalled 420.6 mm, accounted for 41.0% of the annual total. Although the total rainfall in 1998 was only slightly higher than the historical (1985-1998) record of Kedu Township Weather Station, the great frequency of intense storms caused serious runoff. The Kelang River had the largest flood during the past 10 years (Yearbook of Kedu Hydrology Station, 1998).

3.2.3 Maximum, Minimum and Mean Temperatures

The lowest mean monthly minimum temperatures were 0.9˚C and –0.5˚C in 1998 and 1999, respectively, which occurred in January. The extreme minimum temperature was –2.5˚C and –4.5˚C in 1998 and 1999, respectively. The highest mean maximum monthly temperatures were 27.4 and 27.3˚C, which occurred in May 1998 and June 1999, respectively. The extreme maximum temperature for both 1998 and 1999 was 31.5˚C, which occurred on 12 and 4 of May 1998 and 1999, respectively. The annual mean temperature over two years was 16.0˚C. The experimental site altitude was 200 m higher than the meteorological station. Adjusting using the saturated air adiabatic lapse rate (0.6˚C/100 m, Cheng Yongsheng *et al*., 1990), the estimated mean annual temperature of the experimental site was 14.8˚C.

3.2.4 Soil Temperature

Soil temperatures at different depths were recorded at 0900 each day. The purpose of the measurement was to indicate the soil temperature trends at different depths (5, 10, 15 and 20 cm), as shown in Fig. 3.2.3.



There were no significant differences in the temperatures recorded, but the annual trends followed the expected seasonal pattern. The 20 cm temperature was always the highest and the 5 cm temperature the lowest.

According to research results on soil temperature for maize germination, the suitable germination soil temperature ranges are 18-25˚C (Crop Plant and Cultivation, 1981). Therefore, soil temperature was not a problem at Wang Jia Experimental Site. In late May, when the maize was planted, the soil temperature was within the suitable range. For example, in May, the mean soil temperatures in 1998 were 20.6, 20.6, 21.3 and 21.9˚C and in 1999 17.4, 17.9, 18.4 and 19.0˚C at the depths of 5, 10, 15 and 20 cm, respectively.

3.2.5 Air Temperature

Air temperature varies from location to location and hour to hour. Even over the year, there were not marked differences between 1998 and 1999. However, when considered as monthly means, seasonal trends were very clear (Fig. 3.2.4).

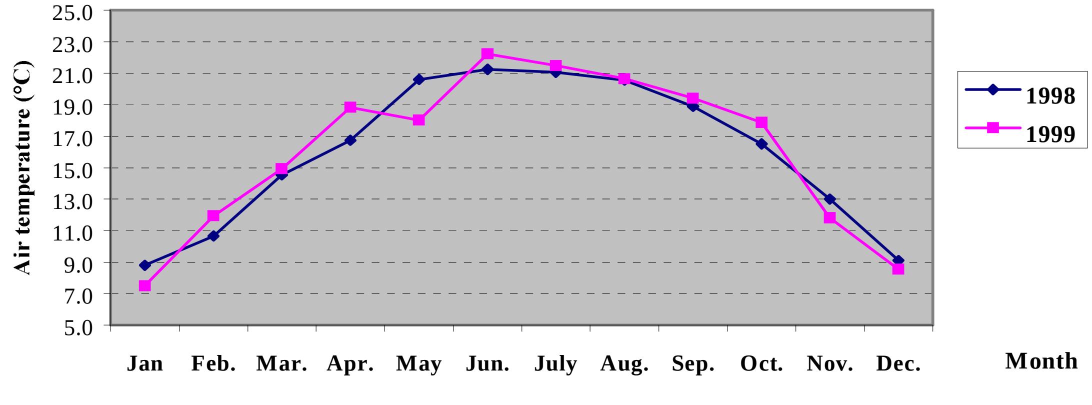


Fig. 3.2.4 Monthly mean air temperature at 0900 h at Kelang weather station in 1998-1999

The temperature in May 1999 decreased, because there were many rain days with cloud cover. There were 18 days with rain, while just 11 days with rain in May 1998. The temperature was 2.6˚C lower than in 1998. Conversely, in June, there was less rainfall than in 1998, which caused the monthly temperature to be 0.9˚C higher than in 1998. The higher temperature and lower rainfall in June 1999 led to lower relative humidity (Table 3.1.1) and contributed to major problems for maize seedlings (Chapter 3.4.1).

3.3.6 Relative Humidity

After calculating using the Hygrometric Tables (using the mean dry and wet bulb records each month) relative humidity in 1998 and 1999 at Kelang village are shown in Fig. 3.2.5.

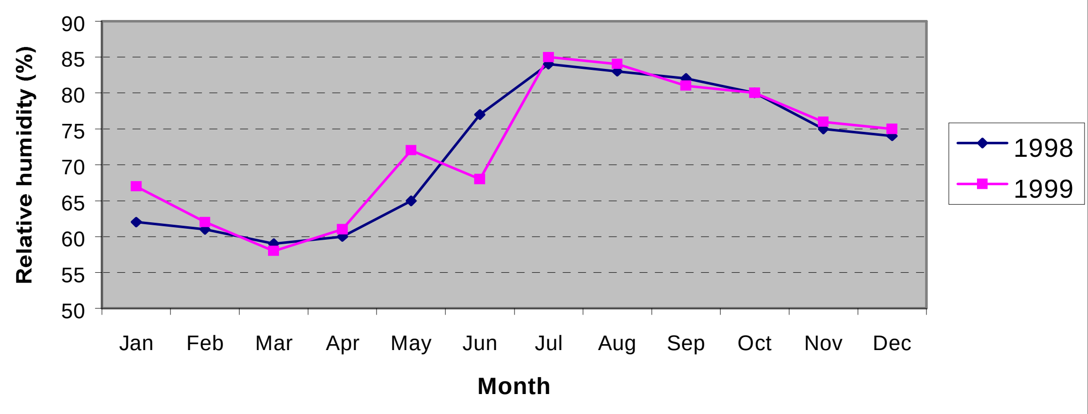


Fig. 3.2.5 Mean relative humidity at 0900 h at Kelang in 1998 and 1999

The relative humidity varied with the rainfall and air temperature. In 1999, because of the lower rainfall, mean relative humidity in June was 68%, which was lower than the same month in 1998 (77%). Conversely, in May 1999, there was more rainfall in May 1998, the mean relative humidity (72%) was higher than the same month in 1998 (65%).

3.3 Soil Measurements in Experimental Plots

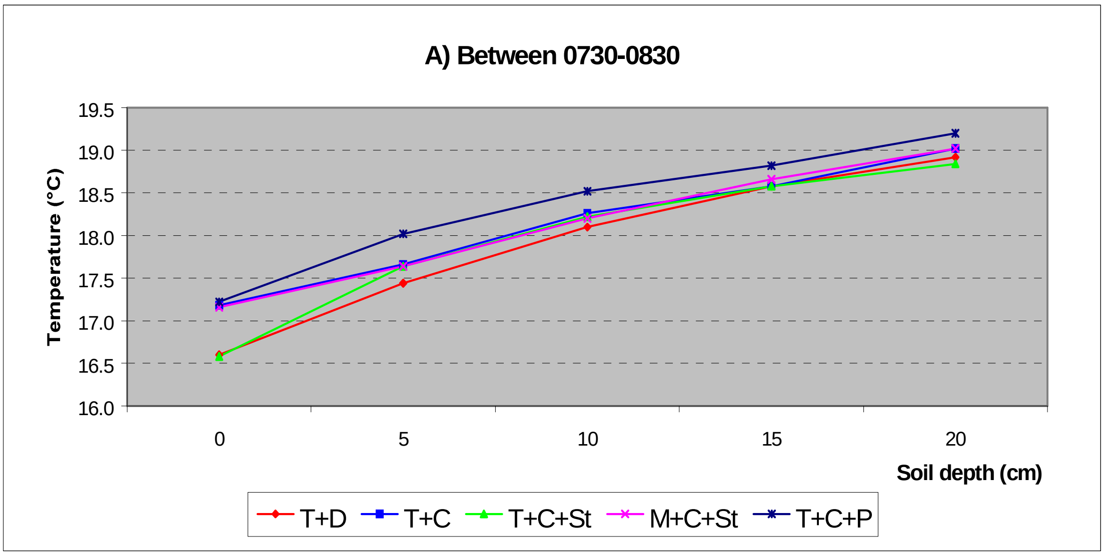
Soil measurements were carried out during the cropping season in 1998 and 1999, respectively. There was no irrigation at the early stage in the 1998 season, while there was irrigation in 1999. In 1999, in order to compare cultivation techniques under different irrigation methods, another experiment with the same treatments, but no irrigation, was carried out. All measurements were taken according to the measurement schedule. There were just four measurement occasions for the non-irrigated experiment. The measurement results for individual experiments are discussed in this section.

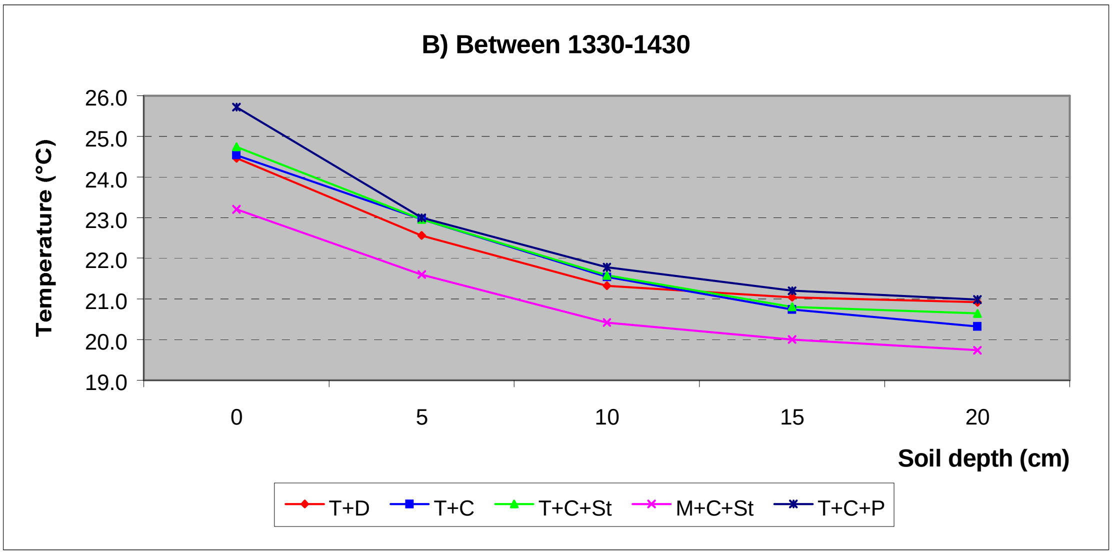
3.3.1 Effect of Cultivation Treatment Techniques on Soil Temperature

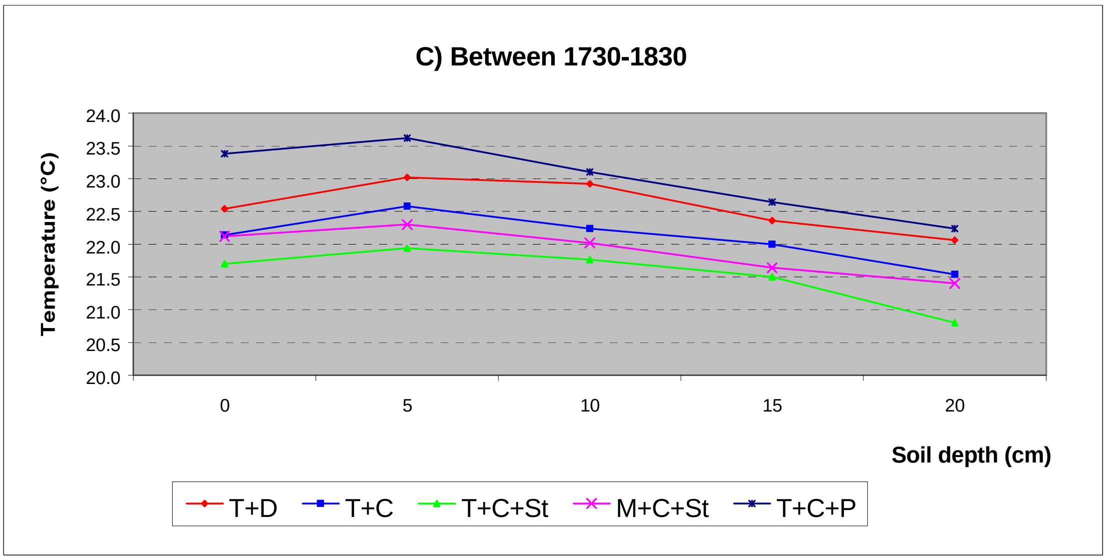
1) Effects of cultivation techniques on soil temperature over season

Soil temperature was measured concurrently every two weeks after sowing, with soil moisture during both growing seasons. On each date, soil temperature was recorded three times during the day (0730-0830, 1300-1400 and 1730-1830). This procedure allowed seasonal changes between treatments to be determined and provided data for the study of diurnal variations in soil temperature. Five replicate readings per plot were taken at each measurement time and seasonal plot means were calculated (Figs. 3.3.1 A, B and C).

Fig. 3.3.1 Effects of cultivation techniques on mean soil temperatures at different depths during the growing season in 1998







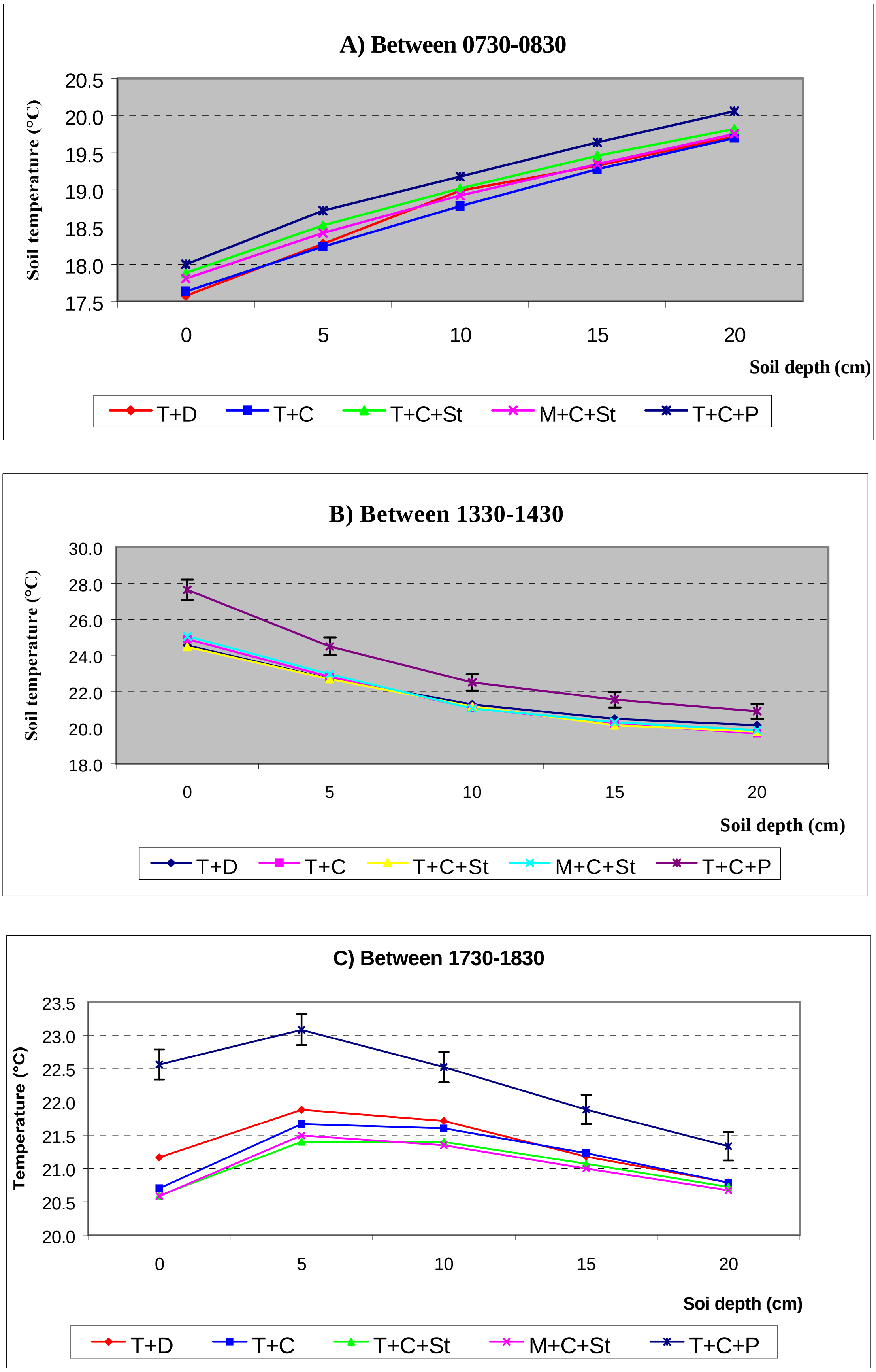
Considering the 1998 data, polythene mulch clearly exhibited the highest temperature on three occasions during a day, particularly in the early growth stage (from germination to 45 days). The polythene mulch treatment had higher temperatures at all soil depths, especially the surface soil (0 cm) by 2.5^{o}C. The polythene mulch effect on soil temperature in the morning was not significantly higher at different depths, even though temperatures were always higher than other treatments. However, the data indicated that heat can be efficiently retained under the polythene mulch. The effects of polythene mulch on temperature were very marked on sunny afternoons. The temperature under the polythene mulch was significantly higher by 4-5^{o}C than other treatments (n = 15, F = 6.813, P<0.01, $LSD_{0.05}$ = 2.45). This effect was maintained to the evening.

The effect of the polythene mulch on daytime temperatures through the early part of the season may possibly be explained by canopy development. At the start of the season, when canopy cover was minimal, the effect of the polythene mulch on soil temperatures would have been at a maximum, as the soil would have been fully exposed to solar radiation. As the canopy developed, the soil surface became increasingly shaded and therefore the mulch had less influence on soil thermal conditions.

Straw mulch also affected soil temperatures in the day. Soil temperature increased very slowly because of the straw cover. The main reason was probably that the straw traps air and air pockets donot transmit the heat as efficiently. The soil temperature was 2-3˚C lower than plastic mulch during day time. On the other hand, the straw cover maintained soil temperature at night. The surface soil temperatures were always 0.5-1.0˚C higher than the control treatments (T+D), particularly in the morning measurements. After 60 days, because of the leaf canopy development and sufficient rainfall, the effects of polythene covering become lessened and temperature differences were not significantly different.

Soil temperature and different cultivation techniques were measured seven times in the 1999 cropping year. These results were presented in Figs. 3.3.2A, B and C).

Fig. 3.3.2 Effects of cultivation techniques on mean soil temperatures at different depths in 1999



In 1999, similar effects with polythene mulch occurred, with the highest temperatures observed at the beginning of the growing season. However, the magnitude of the difference between polythene mulch and the other treatments was less than in 1998. The polythene much treatment temperatures were markedly higher. In May 1999, there was more rainfall than in May 1998 (115.5 versus 65.6 mm), ensuring the maize had good germination. However, in June 1999, the rainfall was less than at the same time in 1998 (81.1 versus 209.4 mm). The lower rainfall caused drier weather and higher temperatures, which led to soil temperatures of all treatments being 3-4℃ higher than in 1998. Therefore, polythene mulch had the highest temperature compared with the other treatments. Soil temperatures under different cultivation techniques behaved significantly differences during the day time (at 0730-0830, no significant difference; at 1330-1430, $n = 7$, $F = 35.486$, $P < 0.01$, $LSD_{0.05} = 2.15$; at 1730-1830: $n = 7$, $F = 14.384$, $P < 0.05$, $LSD_{0.05} = 1.85$). The individual measurement results are discussed below.

<u>2) Effects of cultivation techniques on individual soil treatment measurement</u>

In 1998, because of instrument limitations, soil temperatures in the treatment plots were only measured on five occasions. Soil temperature at different depths (0, 5, 10, 15 and 20 cm) during different measurement periods (0730-0830, 1330-1430 and 1730-1830) are presented in Fig. 3.3.3 (1 and 2). In 1999, the measurements were carried out every two weeks after maize germination, in total seven times during the whole growth stage. The results are presented in Fig. 3.3.4 (1 and 2).

Based on the individual measurements during the growth stages in 1998 and 1999, the main treatment methods that influenced soil temperature were the covering methods. Significant differences were observed only on eight occasions in 1998 and 13 times in 1999, and only early in the season, when there was little canopy cover.

Fig. 3.3.3-1 Soil temperature at different depths at different measurement times during the 1998 maize growing season, with significant differences (P <0.05) denoted by the star.

A) Soil temperature at 0730-0830 at different depths; B) Soil temperature at 1330-1430 at different depths; C) Soil temperature at 1730-1830 different at depths.

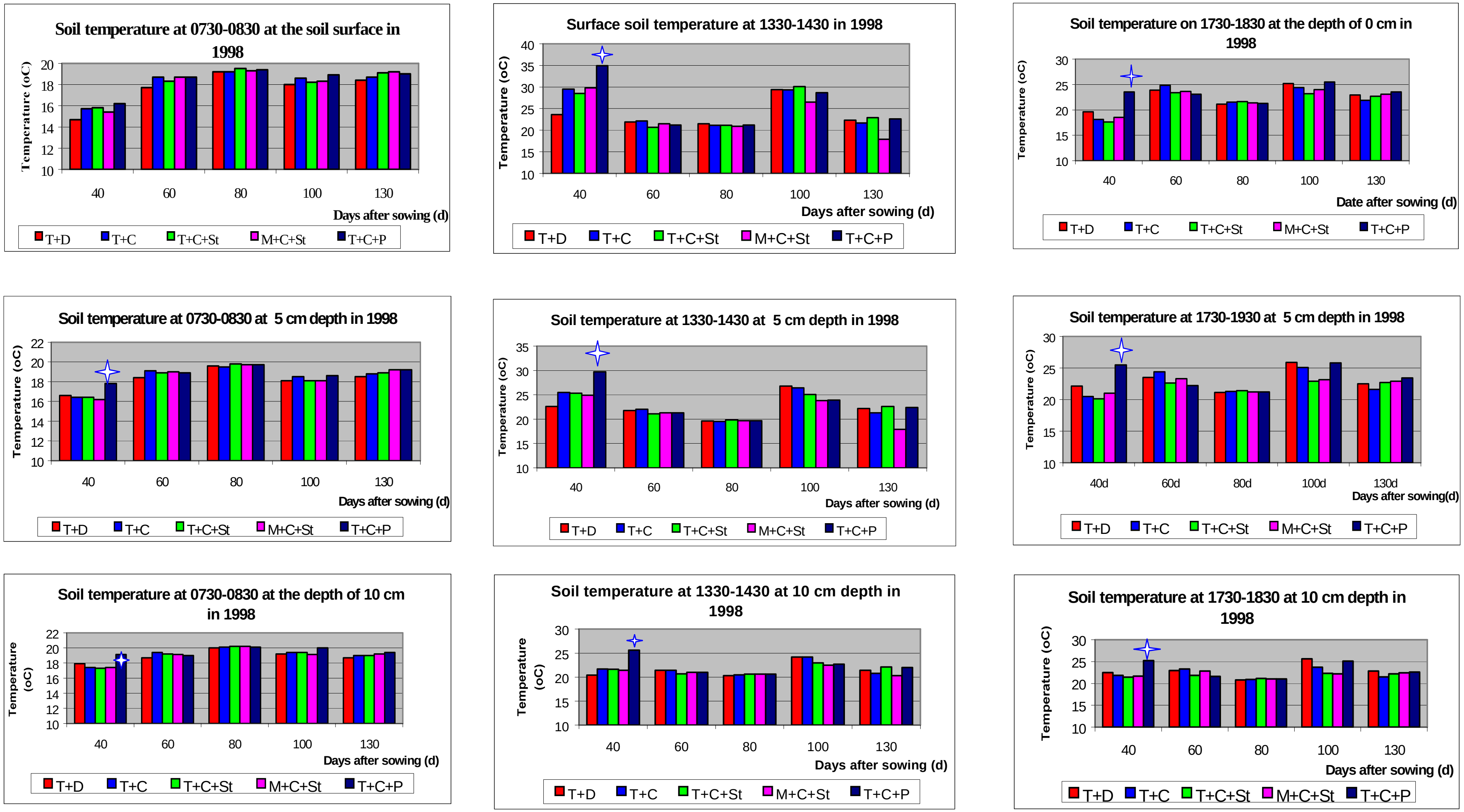


Fig. 3.3.3-2 Soil temperature at different depths at different measurement times during the 1998 maize growing season, with significant differences (P <0.05) denoted by the star.

A) Soil temperature at 0730-0830 at different depths **B) Soil temperature at 1330-1430 at different depths** **C) Soil temperature of 1730-1830 at different depths**

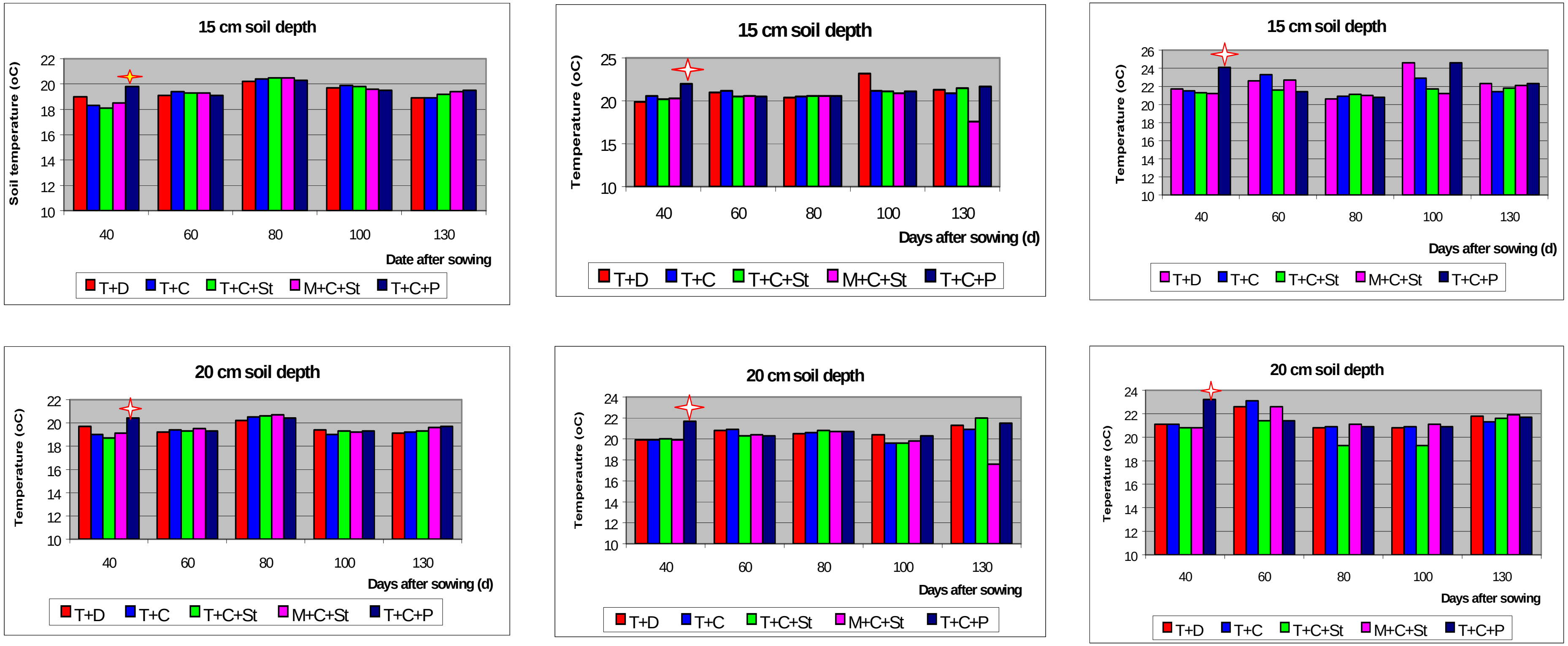


Fig. 3.3.4-1 Soil temperature at different depths on different measurement times during the 1999 maize growing season, with significant differences (P <0.05) denoted by the star.

A) Soil temperature at 0730-0830 at different depths; B) Soil temperature at 1330-1430 at different depths; C) Soil temperature at 1730-1830 at different depths

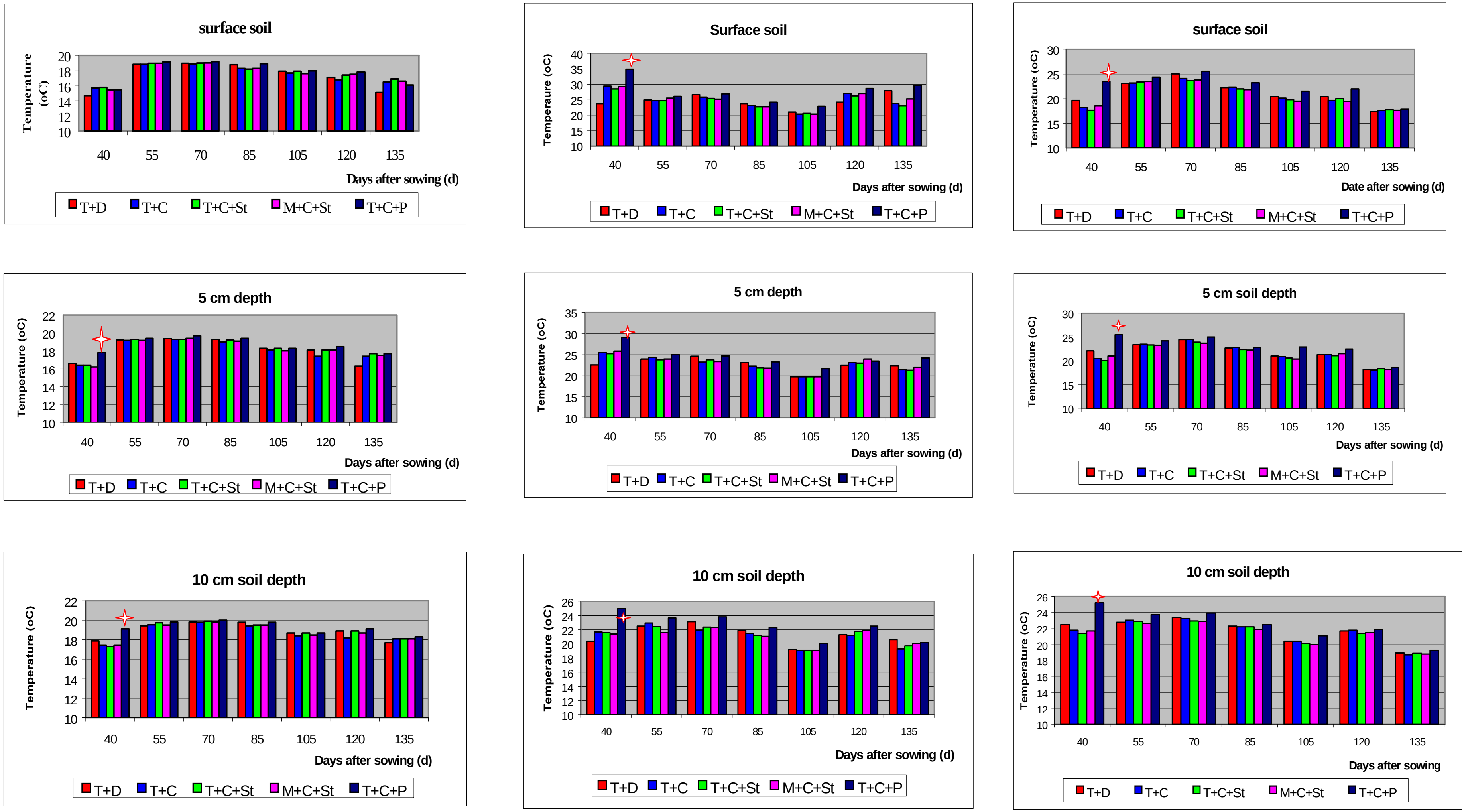
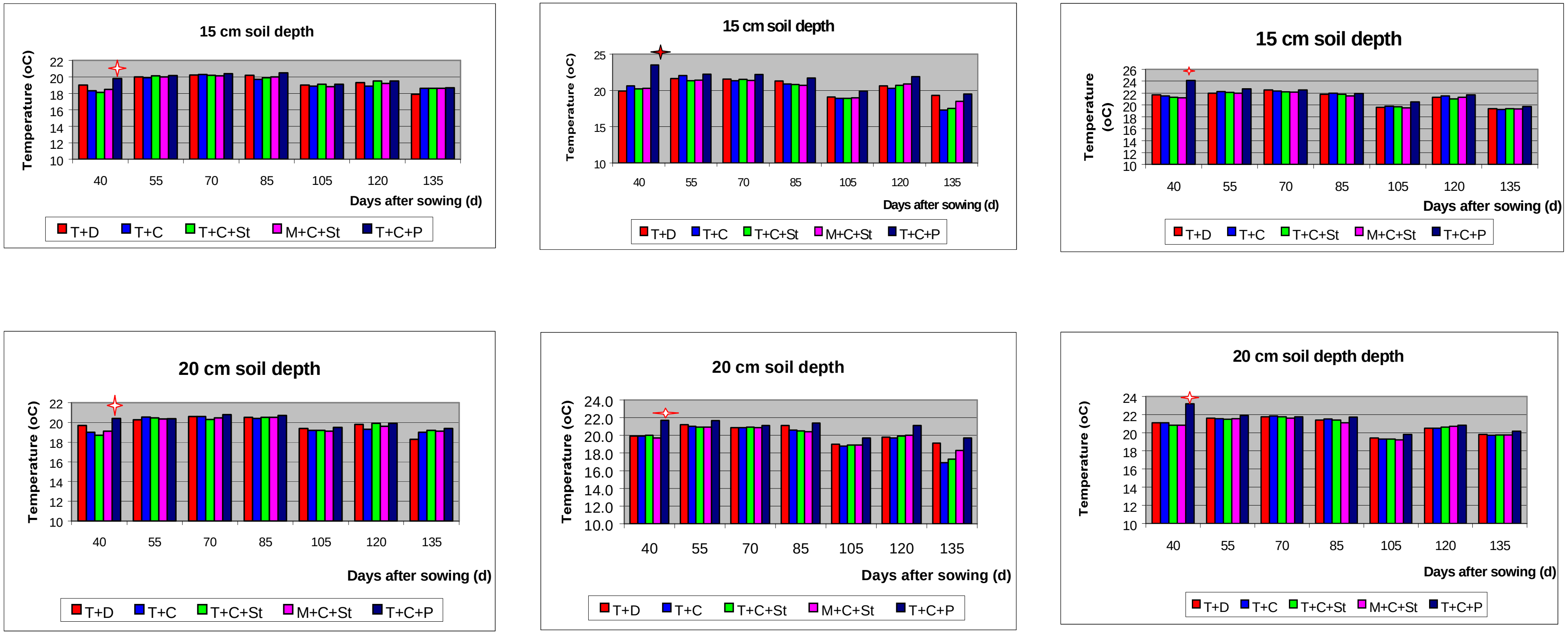


Fig. 3.3.4-2 Soil temperature at different depths on different measurement times during the 1999 maize growing season, with significant differences (P <0.05) denoted by the star.

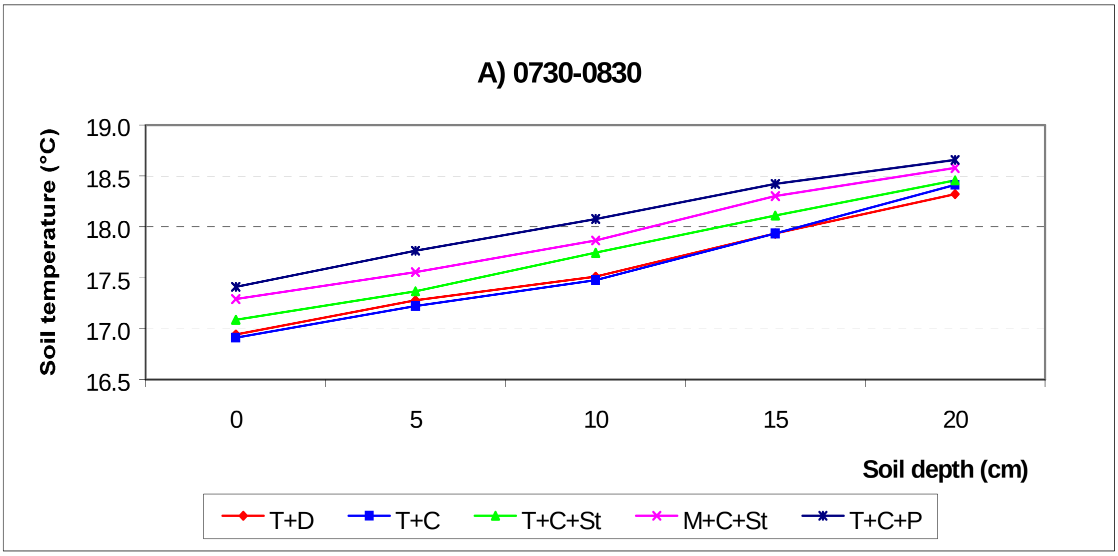
A) Soil temperature at 0730-0830 at different depths, B) Soil temperature at 1330-1430 at different depths, C) Soil temperature at 1730-1830 at different depths.

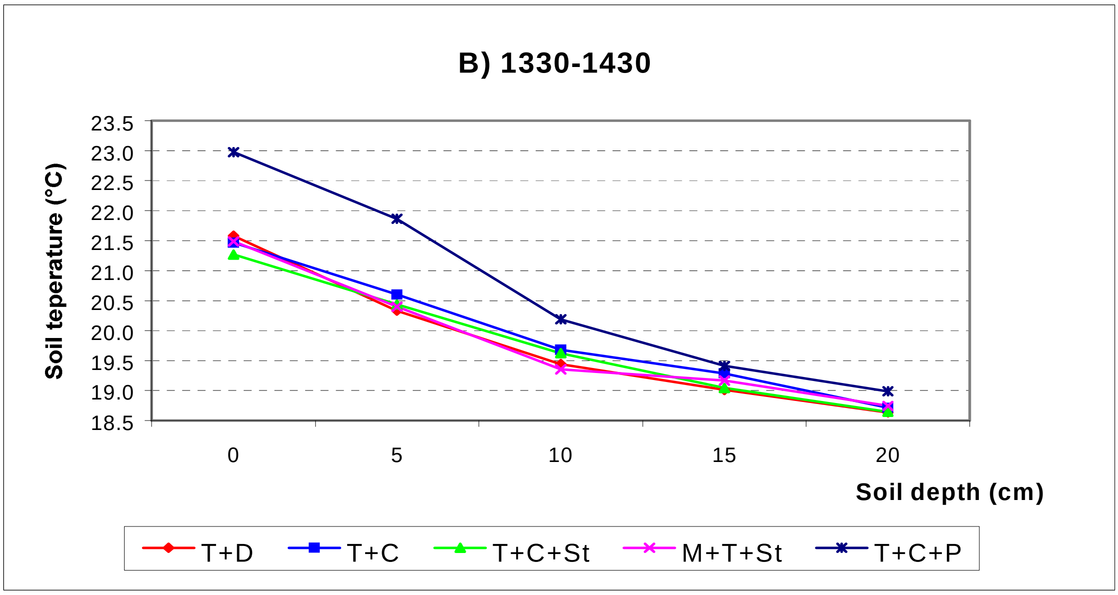


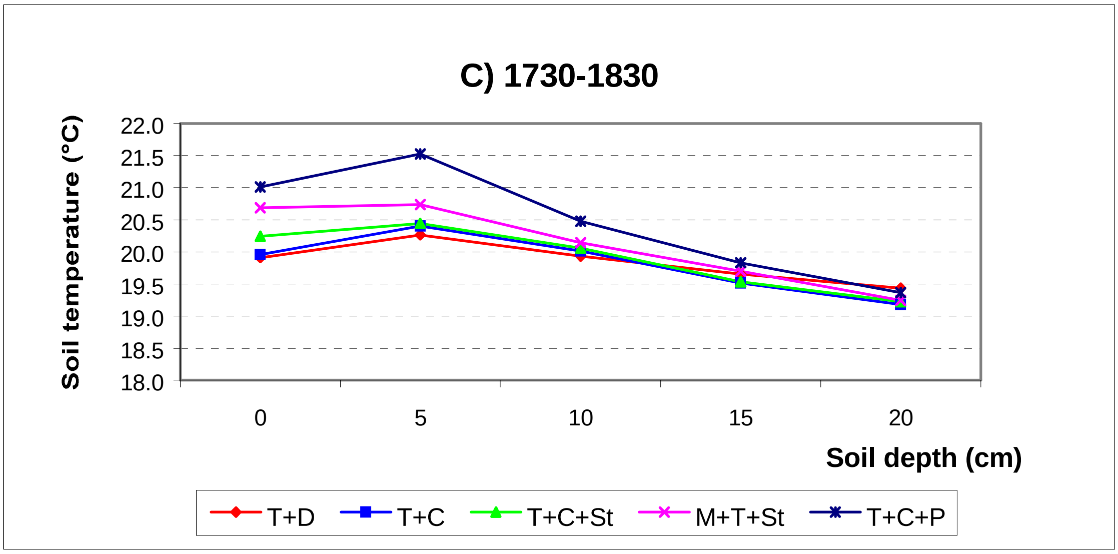
3) Effect of cultivation on soil temperature under non-irrigated treatments in 1999

In 1999, as explained in Chapter 2, the experiment established in 1998 was applied with irrigation water during the sowing and early growth stage. Another experiment with the same treatments, but without irrigation, was established. Just four sessions of soil temperature measurements were taken during the growing season, but similar results as 1998 were obtained (Figs. 3.3.5 A, B and C).

Fig. 3.3.5 Cultivation treatment effects on soil temperature under non-irrigation treatments (A – 0730-0830; B – 1330-1430; C – 1730-1830)







The non-irrigated experiment with the same treatments as the 1998 experiment was not located at exactly the same place. This may have caused some differences. The soil temperatures in both the 1998 and 1999 experiment had similar trends. In 1999, some similar results were observed. For instance, the soil temperature at 0 and 5 cm, under polythene and straw mulch were higher by 0.5-1.0℃ than the control at different depths in the morning (for 0 cm, $n = 3$, $F = 34.99$, $P < 0.01$, $LSD_{0.05} = 0.58$; for 5 cm: $n = 3$, $F = 16.84$, $P<0.01$, $LSD_{0.05} = 0.65$). The order of the temperature for different treatments was the same as 1998, which were T+C+P > M+C+St > T+C+St > T+C > T+D. In the afternoon, the straw mulch cover lagged heat transfer and the temperature order changed to: T+C+P > T+C > T+D > T+C+St > M+C+St. The polythene mulch had significantly higher temperatures at 0 and 5 cm than any other treatments by 2.5-3.0℃. During the evening, polythene had significantly higher temperatures than T+D, T+C, T+C+St and M+C+St at 0 and 5 cm depth.

4) Summary of the cultivation treatment effects on soil temperatures

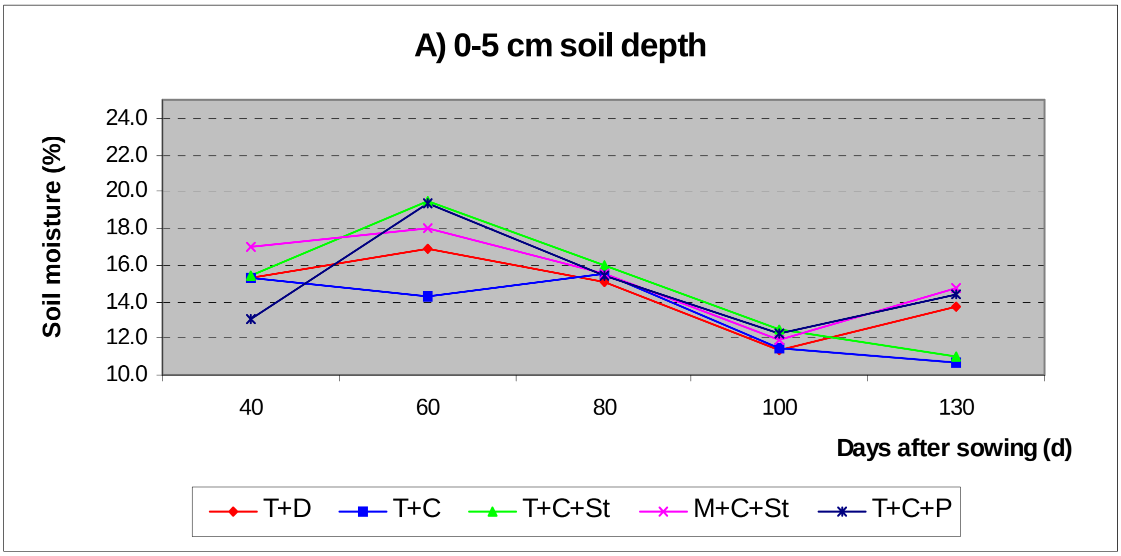
Some notable effects of cultivation techniques on soil temperatures can be observed from the two experimental years. Firstly, polythene mulch markedly increased soil temperature during the early crop growth stage, in comparison to straw mulch. As the canopy developed, the effects and the differences became less. After 40 days, there were no significant differences between mulch and non-mulch treatments. Straw mulch caused lower soil temperatures during day time, but maintained higher temperatures during night. Soil temperature was particularly variable when the soil was dry, especially the soil with no mulch.

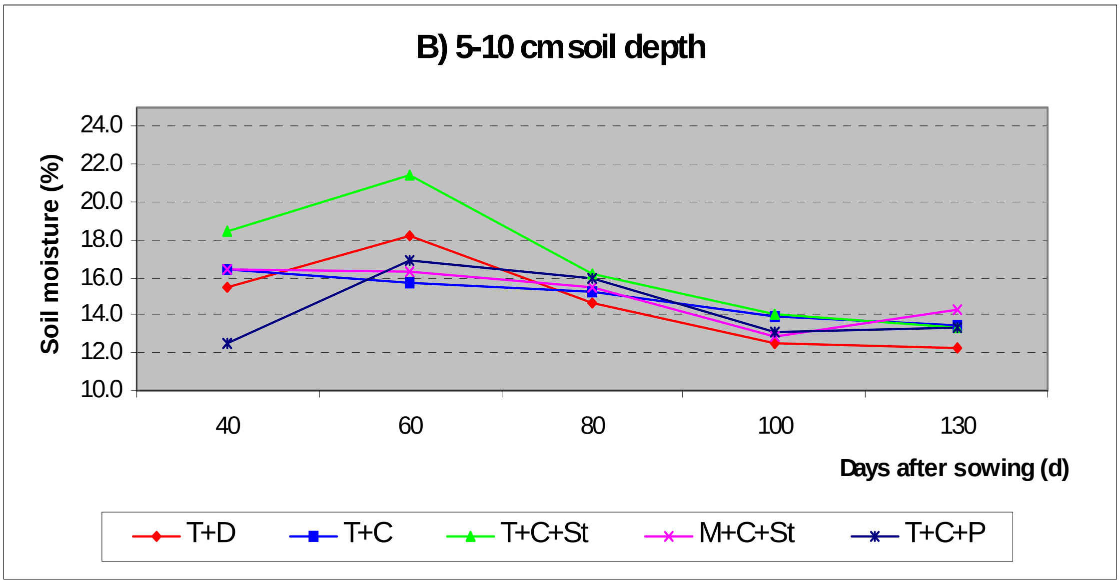
3.3.2 Effect of Cultivation Treatment Techniques on Soil Moisture

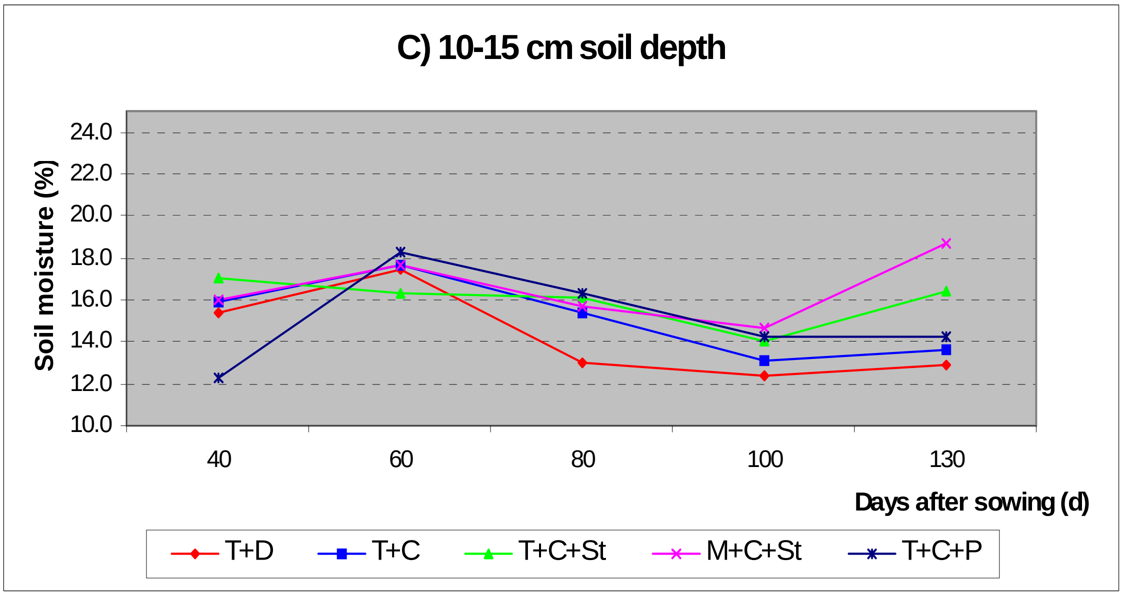
1) Effects of cultivation techniques on soil moisture

Soil moisture measurements were taken on each plot at ~20 day intervals in 1998 and the parameters were recorded five times during the growing season (Figs. 3.3.6 A, B and C).

Fig. 3.3.6 Soil moisture at three different soil depths under different cultivation techniques in the 1998 growing season, A: 0-5, B: 5-10 and C: 10-15 cm soil depth





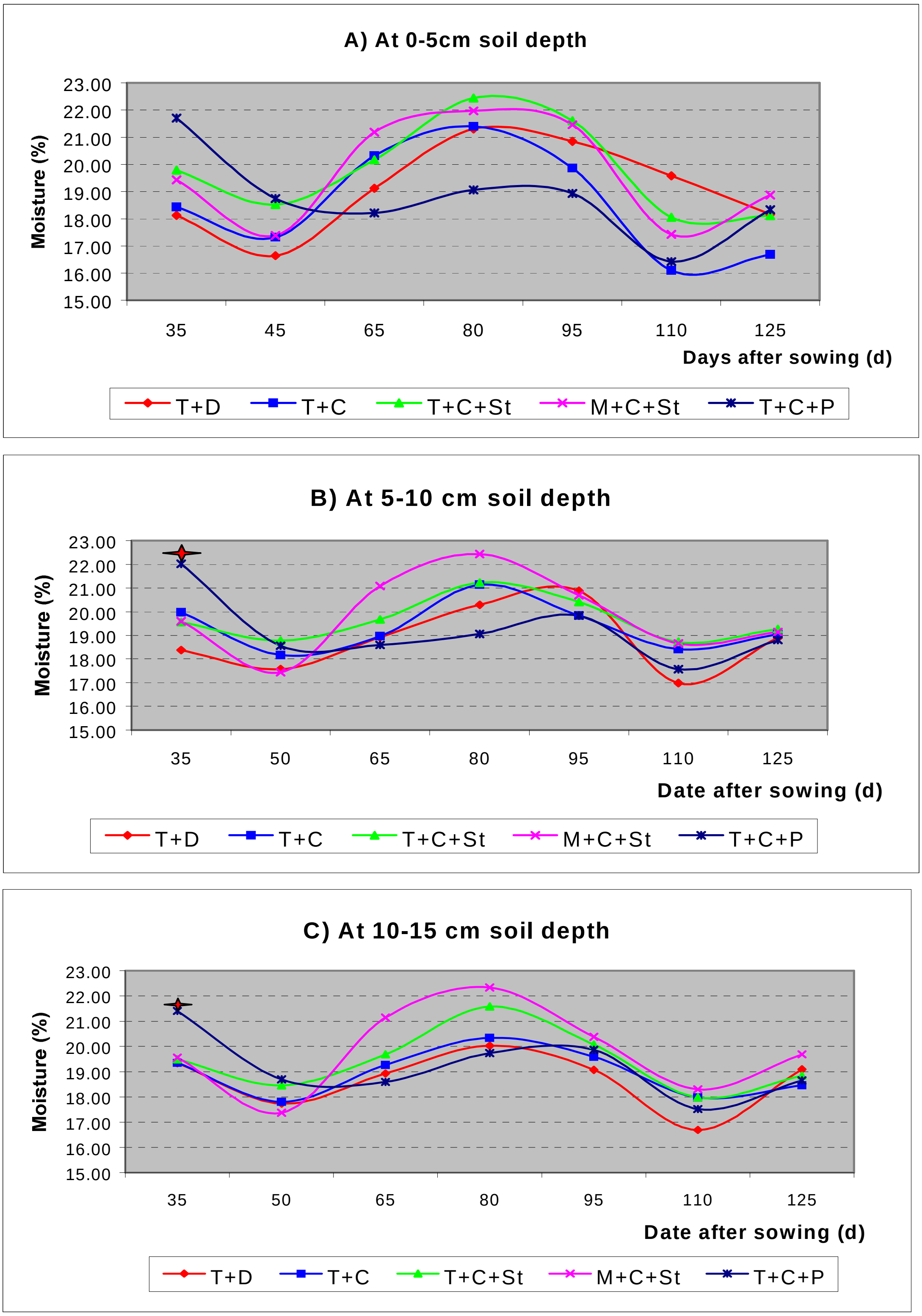


Compared with polythene mulch based on 40 day of measurement, treatments M+C+St and T+C+St contained significantly more soil moisture than polythene at 0-5 and 5-10 cm soil depths (at 0-5 cm: n = 15, F = 6.457, P <0.05, $LSD_{0.05}$ = 1.85%; at 5-10 cm: n = 15, F = 5.457, P <0.05, $LSD_{0.05}$ = 2.15%). The mean soil moisture was 5-7% higher than polythene mulch. When the rainy season comes (60 days after sowing), the moisture under different covers was very similar and changed with rainfall.

Based on the soil moisture results, some clear results on the effects of mulch were obtained. Before covering, if there was insufficient rainfall or irrigation before placing the cover material, the polythene mulch did not have any beneficial effect on soil moisture. Conversely, if there was sufficient soil moisture before placing plastic mulch, polythene prevented rainfall infiltration, causing lower soil moisture than straw mulch, even when there was rainfall after sowing. These effects on soil moisture were maintained throughout the rainy season. After water infiltration, soil moisture under polythene mulch contained the highest moisture at 60 days after sowing. Straw mulch prevented direct solar radiation to the soil surface and efficiently decreased evaporation, which helped maintain relatively lower soil temperatures. It also maintained the significantly higher soil moisture than polythene at the early sowing stage, when there was sufficient rainfall.

In 1999, the covering materials were put on immediately after irrigation (3 litres per pit). Results of seven occasions of measurements results are shown in Figs. 3.3.7 (A, B and C).

Fig. 3.3.7 Effects of cultivation techniques on soil moisture with early irrigation in the 1999 growing season



Based on the 1999 data, the results were very different from the 1998 season. Polythene mulch exhibited significantly more soil moisture than the other treatments ($n = 45$, $F = 18.01$, $P < 0.05$, $LSD_{0.05} = 0.39\%$) at the early stage. The soil moisture was 2-3% (21.44 versus 18.61%) higher under polythene mulch than the other treatments. The straw mulch also efficiently maintained soil moisture. There was significantly more soil moisture under the straw mulch treatments (T+C+St and M+C+St) than the control treatment (T+D), but these effects were mainly exhibited at the early growth stage. When the whole growing season measurement results were selected to compare, these phenomena were very clear (Table 3.3.1).

Table 3.3.1 Mean soil moisture under different cultivation techniques during whole growth stages 1999, the data have been analysed by repeat ANOVA with significant differences ($P \leq 0.05$) denoted by different letters. The values are the means of the 7 measured points for each treatment in one block

Treatment	Soil moisture (%)			Mean
	0-5 cm	5-10 cm	10-15 cm	
T+D	19.11 a	18.84 a	18.70 a	18.88 a
T+C	18.59 a	19.36 ab	18.97 a	18.97 a
T+C+St	19.82 b	19.66 b	19.45 b	19.64 b
M+C+St	19.68 b	19.86 b	19.83 b	19.79 b
T+C+P	18.77 a	19.20 ab	19.21 ab	19.06 a
In which: 0-5 cm, $n = 35$, $F = 18.01$, $P < 0.01$, $LSD_{0.05} = 0.53$; 5-10 cm, $n = 35$, $F = 25.145$, $P < 0.01$, $LSD_{0.05} = 0.56$; 10-15 cm, $n = 35$, $F = 21.365$, $P < 0.01$, $LSD_{0.05} = 0.47$; Mean value, $n = 105$, $F = 8.46$, $P < 0.01$, $LSD_{0.05} = 0.29$.				

If soil moisture is considered over the whole growing season, general trends under different treatments can be observed. Compared with all treatments, if there was enough water supplied before mulch, the efficiency for soil moisture retention was: M+C+St > T+C+St > T+C+P > T+C > T+D. Straw mulch treatments (M+C+St and T+C+St) contained significantly higher soil moisture during the whole growth stage. The mean soil moisture from May-October under T+C+St and M+C+St were 19.8 and 19.6%, compared to 18.9, 19.0 and 19.1% under T+D, T+C and T+C+P treatments, respectively. This indicated that straw material can maintain higher soil moisture contents, even it did not have as much ability to retain moisture as under polythene during the whole maize growing seasons. The treatment M+C+St had the highest ability for moisture retention during the whole growth stages.

2) Effects of cultivation on soil moisture at different maize growth stages

The effects of different cultivation techniques on soil moisture at different individual measurements in 1998 and 1999 are presented in Table 3.3.2.

Table 3.3.2 Individual soil moisture measurements at different depths during the growth stages in the 1998 and 1999, the data have been analysed by repeat ANOVA with significant differences (P ≤0.05) denoted by different letters. The values are the means of the 5 measured points for each treatment in one block

Time	Treatment	1998			1999		
		0-5cm	5-10 cm	10-15cm	0-5cm	5-10 cm	10-15cm
1	T+D	15.27 ab	15.47 b	15.40 b	18.12 a	18.38 a	19.33 a
	T+C	15.33 ab	16.40 bc	15.93 bc	18.43 ab	19.97 ab	19.35 ab
	T+C+St	15.37 ab	18.50 c	17.07 c	19.79 ab	19.56 ab	19.49 ab
	M+C+St	16.97 b	16.43 bc	16.03 bc	19.43 ab	19.59 ab	19.59 ab
	T+C+P	13.00 a	12.47 a	12.30 a	21.70 b	22.02 b	21.40 b
2	T+D	16.87 ab	18.27 b	17.47 ab	16.64 a	17.57 ab	17.74 a
	T+C	14.23 a	15.70 a	17.70 ab	17.32 ab	18.17 ab	17.80 ab
	T+C+St	19.50 c	21.43 c	16.30 a	18.52 ab	18.78 ab	18.46 ab
	M+C+St	17.97 ab	16.33 ab	17.67 ab	17.39 ab	17.43 a	17.37 ab
	T+C+P	19.37 c	16.87 ab	18.27 b	18.75 b	18.56 b	18.69 b
3	T+D	15.13 a	14.60 a	12.97 a	19.12 ab	18.92 ab	18.93 ab
	T+C	15.53 ab	15.27 ab	15.37 bc	20.31 ab	18.97 ab	19.27 ab
	T+C+St	16.03 b	16.23 b	16.07 bc	20.17 ab	19.67 ab	19.69 ab
	M+C+St	15.50 ab	15.43 ab	15.70 bc	21.18 b	21.08 b	21.14 b
	T+C+P	15.43 ab	15.97 ab	16.33 c	18.21 a	18.59 a	18.60 a
4	T+D	11.37 a	12.53 a	12.43 a	21.30 b	20.29 ab	20.03 ab
	T+C	11.50 ab	13.93 ab	13.07 ab	21.40 b	21.14 b	20.34 ab
	T+C+St	12.47 b	14.07 b	14.00 ab	22.44 c	21.22 bc	21.59 b
	M+C+St	11.90 ab	12.90 ab	14.63 b	21.97 bc	22.43 c	22.34 c
	T+C+P	12.20 ab	13.13 ab	14.27 ab	19.06 a	19.06 a	19.73 a
5	T+D	13.77 b	12.27 a	12.87 a	20.85 ab	20.18 ab	19.07 a
	T+C	10.67 a	13.50 ab	13.67 ab	19.87 ab	19.84 ab	19.59 ab
	T+C+St	10.97 ab	13.37 ab	16.43 c	21.60 b	20.41 ab	20.07 ab
	M+C+St	14.73 c	14.30 b	18.73 c	21.46 b	20.69 b	20.38 b
	T+C+P	14.43 c	13.30 ab	14.23 b	18.93 a	19.83 a	19.87 ab
6	T+D	No measurement data in 1998			18.58 a	17.98 a	16.69 a
	T+C				17.10 a	18.41 a	17.98 a
	T+C+St				18.06 a	18.72 a	17.98 a
	M+C+St				17.43 a	18.65 a	18.30 a
	T+C+P				17.42 a	17.57 a	17.52 a
7	T+D	No measurement data in 1998			18.16 ab	18.89 a	19.09 a
	T+C				16.69 a	19.05 a	18.46 a
	T+C+St				18.12 ab	19.26 a	18.84 a
	M+C+St				18.87 b	19.14 a	19.69 a
	T+C+P				18.33 ab	18.80 a	18.65 a

Considering the individual measurement results, there were still significant differences in different soil layers under the same treatment, although there were marked differences among cultivation techniques during the middle and later growing stages. These indicated that different cultivation methods and covering materials had different effects in different soil layers during growth stages. Different cultivation techniques may influence soil structure, in the long-term.

3) <u>Comparison of the cultivation treatment effects under irrigation and non-irrigation</u>
The effects of cultivation treatment effects on soil moistures were compared generally using the measurement results under irrigation and non-irrigation treated methods in 1999. There were only four occasions of soil moisture measurements taken on the non-irrigation treatment experiment. Here the first measurement (in June) is selected for comparison (Table 3.3.3).

Table 3.3.3 Effects of cultivation on soil moisture under irrigated and non-irrigated treatments in June 1999 at Wang Jia Experimental Site, the data have been analysed by ANOVA with significant differences (P ≤0.05) denoted by different letters. The values are the means of the 5 measured points for each treatment in one block

Treatment	0-5 cm		5-10 cm		10-15 cm	
	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated
T+D	18.12 a	12.63 a	18.38 a	12.94 a	19.33 a	14.43 a
T+C	18.43 a	13.49 b	19.97 ab	13.52 b	19.35 a	14.22 a
T+C+St	19.79 ab	14.50 bc	19.56 ab	14.57 bc	19.49 a	15.33 ab
M+C+St	19.43 ab	14.70 bc	19.59 ab	14.69 bc	19.59 a	15.17 ab
T+C+P	21.70 b	15.99 c	22.02 b	15.40 c	21.40 b	15.61 b

In which: Irrigation: 0-5 cm, n = 5, F = 16.235, P <0.01, $LSD_{0.05}$ = 3.25;
5-10 cm, n = 5, F = 18.756, P <0.01, $LSD_{0.05}$ = 3.60;
10-15 cm, n = 5, F = 14.897, P <0.01, $LSD_{0.05}$ = 1.80;
Non-irrigation: 0-5 cm, n = 5, F = 26.487, P <0.01, $LSD_{0.05}$ = 2.48;
5-10 cm, n = 5, F = 15.347, P <0.01, $LSD_{0.05}$ = 1.87;
10-15 cm, n = 5, F = 21.365, P <0.01, $LSD_{0.05}$ = 1.16.

Although it was not appropriate to directly compare statistics, the same cultivation effects on soil moisture were found both on irrigated and non-irrigated treatments. Both the irrigation and non-irrigation treatments produced evidence that different cultivation techniques influenced soil moisture. They indicated that the polythene retained soil moisture more efficiently than other treatments. Straw mulch exhibited higher abilities to maintain soil moisture, especially under non-irrigation conditions.

4) Summary of effects of cultivation techniqures on soil moisture

Considering the overall seasonal means for each treatment, the effects of the different cultivation techniques were clear. The combined treatment with polythene and straw mulch markedly increased soil moisture. Contour cultivation with polythene mulch had noticeable effects on maintaining soil moisture, when the soil contained sufficient moisture before polythene emplacement. Soil moisture was significantly higher than other treatments at the early growth stage. Straw mulch was not as effective as polythene at the early growth stage, but both contour and minimum cultivation combined with straw mulch had a significantly higher mean soil moisture during the whole growing season, compared with unmulched and polythene mulch treatments. Especially, when there was insufficient rainfall or irrigation before and after planting, straw mulch had a noticeable ability to maintain the finite soil moisture. In order to form a good soil moisture condition under mulching, irrigation was essential before covering if the soil was very dry, especially with polythene mulch. The effect of polythene depended on how much moisture was contained in the covered soil.

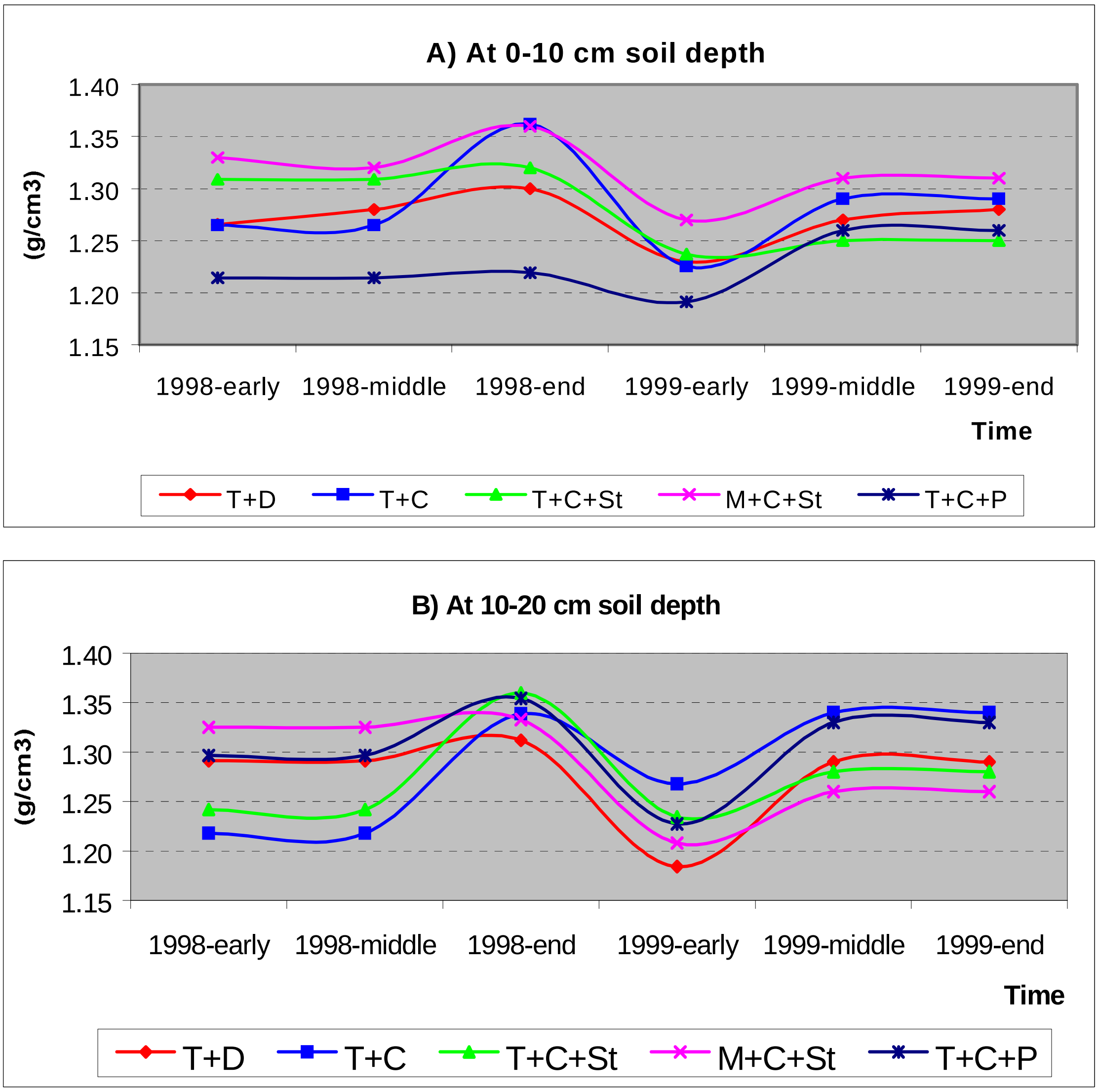
3.3.3 Effect of Cultivation Techniques on Soil Bulk Density

Soil bulk density measurements in 1998 and 1999 were taken three times (early, middle and end of the growing season) for each cultivation treatment plot for both irrigation and non-irrigation experiments in 1999, while just in non-irrigation experiments in 1998. The bulk density results from 1998-1999 and the effects on bulk density by irrigation and non-irrigation at two depths (0-10 and 10-20 cm) are presented in this section.

1) Effects of cultivation techniques on soil bulk density

Soil bulk densities measurement results of different cultivation techniques at different soil depths (0-10 and 10-20 cm) during 1998 and 1999 cropping season are shown in Fig. 3.3.8 (A and B).

Fig. 3.3.8 Effects of cultivation techniques on soil bulk density during 1998 and 1999 cropping season (A: 1-10 cm; B: 10-20 cm soil depth)



During the 1998 cropping season, within the 0-10 cm soil depth, bulk densities in the different treatments were variable ($n = 3$, $F = 16.55$, $P < 0.01$, $LSD_{0.05} = 0.12$). Generally, owing to the absence of primary tillage treatment, the minimum tillage plots generally had the highest bulk density values at the start of the season and did not change very much during the whole growing season. The polythene mulch had the lowest soil bulk density during the whole season at 0-10 cm depth. The main reason may be because the polythene protected the surface soil from raindrop impact. This effect can also be found in the straw mulch treatment. The soil bulk density in treatment T+C+St did not noticeably change during the growing season. In the other two treatments (T+D and T+C), the density increased gradually during the whole season.

At 10-20 cm depth, the minimum tillage also had the same trends as in the 0-10 cm depth, with the highest soil density at the beginning stage. It did not change much during the whole season. Other treatments, with field cultivation before sowing, had lower densities in the early and middle growing season.

At the end of the season, soil bulk density values were higher on almost all plots. This exemplifies the role of tillage operations at the start of the season in breaking up and loosening soil. These effects decreased through the season, possibly as a result of compaction through raindrop impact and associated decreases in surface roughness.

During the 1999 cropping season, after two years of cultivation and treatment, soil bulk densities were very different between treatments. With the increase in values overall, treatment differentiation was more difficult. Minimum tillage still had higher bulk densities than any other treatment in the top 10 cm of soil during the whole growing season. Differences in depth were clearer with the measurements taken at the end of the season, with the top 10 cm having a higher bulk density in treatment M+C+St, compared to others at the beginning and middle of the season.

Polythene mulch had the lowest density and was significantly lower than M+C+St treatment at the beginning and middle growth stages ($n = 15$, $F = 19.63$, $P < 0.05$, $LSD_{0.05} = 0.13$). Treatments T+D and T+C had marked increases in density during early and middle growth stages at 0-10 cm soil depth. These results highlight the significant effect of raindrop impact on surface soil structure. Treatment T+C+St maintained a stable lower soil bulk density, especially at the end of the season, as the straw cover efficiently prevented raindrop impact.

At 10-20 cm depth, soil bulk density change was similar for the different treatments. Although there was no significant difference between treatments, the minimum tillage always had the lowest density, while the traditional tillage plus contour planting had the highest bulk density during the growing season. As maize growth progressed, bulk density generally increased. The reason was the bare soil surface was easily compacted by raindrops. Furthermore, intensive cultivation caused fine soil particles to illuviate, which increased compaction.

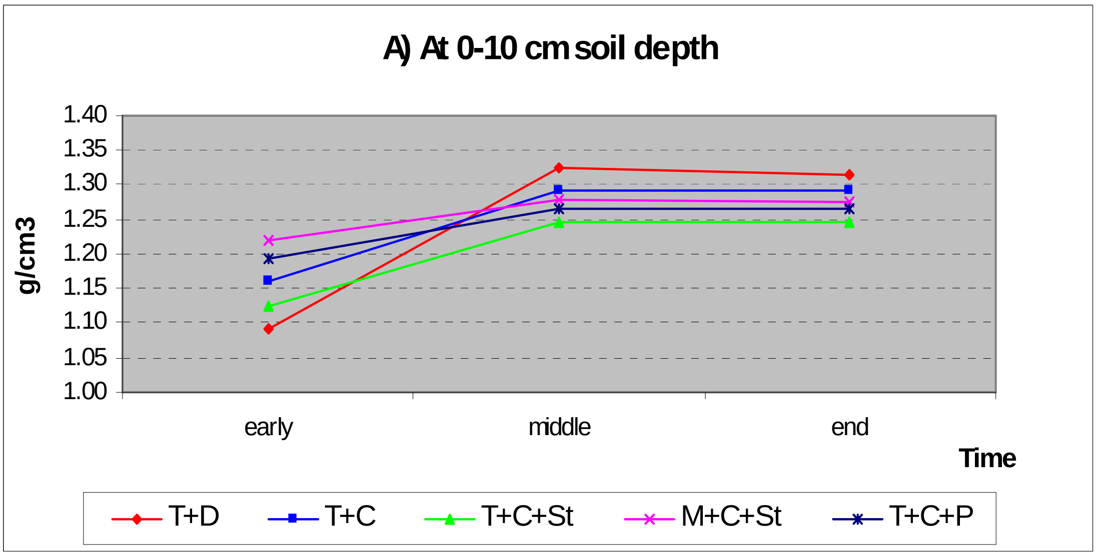
Based on two years of measurements, some general soil bulk density changes under different treatments were evident. The effects of different treatments on soil bulk density in the 0-10 cm soil depth from the beginning of 1998 to the end of 1999 were very significant ($n = 3$, $F = 9.854$, $P < 0.05$, $LSD_{0.05} = 0.09$). The data indicate that straw mulch was beneficial for soil bulk density. After using straw mulch, the density tended to decrease, from 1.31 and 1.33 g cm^{-3} at the beginning of 1998 to 1.25 and 1.31 g cm^{-3} at the end of 1999 for treatments T+C+St and M+C+St, respectively. Other treatments did not benefit soil bulk density. Polythene mulch, which could prevent raindrop impact and maintain a lower soil bulk density than others, also had an increased density from 1.21 (1998) to 1.26 (1999) g cm^{-3}. Polythene mulch had not essentially affected soil structure. For the other two treatments (T+D and T+C, with no cover), the soil bulk density increased from 1.27 and 1.26 kg cm^{-3} to 1.28 and 1.29 kg cm^{-3}, respectively. Cultivation did not have any long term benefit for soil bulk density.

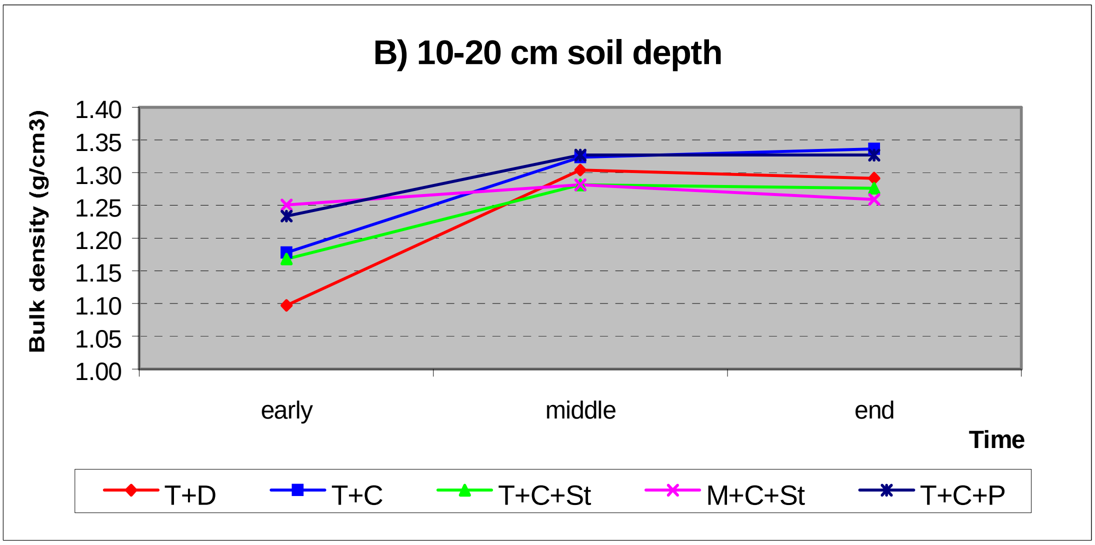
For the 10-20 cm depth soil, bulk density had not been affected as much as the topsoil, but also significantly changed during two years of experiments ($n = 3$, $F = 12.48$, $P<0.01$, $LSD_{0.05} = 0.12$). Besides the treatment M+C+St, which had decreased in density from 1.33 to 1.26 kg cm^{-3}, the other treatments changed within the two years. Mulch, cultivation and the effect of crop root mainly affected topsoil structure.

2) <u>Effects of cultivation techniques on soil bulk density under non-irrigation</u>

Similar effects of cultivation techniques on soil bulk density under non-irrigation conditions were also obtained in 1999 in the experiment with the same cultivation treatment. The changing trends of bulk density at two soil depths (0-10 and 10-20 cm) are shown in Fig. 3.3.9 (A and B).

Fig. 3.3.9 Effects of cultivation techniques on soil bulk density under non-irrigation, which was measured in an experiment with the same cultivation techniques in the 1999 cropping season





Although the two experiments were not located at the same place, the same trends were obtained in both 1998 and 1999 under non-irrigated treatments. This confirmed the cultivation effects on soil bulk density. Table 3.3.4 compares the cultivation effects on soil bulk density under irrigated and non-irrigated treatments.

Table 3.3.4 Comparison of effect of cultivation techniques on soil bulk density under irrigated and non-irrigated treatments in the 1999 growing season (n = 3), the data have been analysed by ANOVA with significant differences (p ≤0.05) for both two irrigation treatments, the values are the means of the 3 blocks for each treatment

Depth (cm)	Treatment	Early		Middle		End	
		Irrigation	Non-irrigation	Irrigation	Non-irrigation	Irrigation	Non-irrigation
0-10	T+D	1.23 ab	1.09 a	1.27 ab	1.33 a	1.28 a	1.31 a
	T+C	1.23 ab	1.16 ab	1.29 a b	1.29 a	1.29 a	1.29 a
	T+C+St	1.24 ab	1.13 ab	1.25 a	1.25 a	1.25 a	1.25 a
	M+C+St	1.37 b	1.31 b	1.35 b	1.28 a	1.32 a	1.29 a
	T+C+P	1.19 a	1.20 ab	1.26 ab	1.26 a	1.26 a	1.26 a
10-20	T+D	1.18 a	1.10 a	1.29 a	1.30 a	1.29 a	1.29 a
	T+C	1.27 ab	1.18 ab	1.34 a	1.32 a	1.34 a	1.34 a
	T+C+St	1.23 ab	1.17 ab	1.28 a	1.28 a	1.28 a	1.28 a
	M+C+St	1.31 b	1.25 b	1.26 a	1.28 a	1.26 a	1.26 a
	T+C+P	1.23 ab	1.23 ab	1.33 a	1.33 a	1.33 a	1.33 a

When considering the results from the same year under irrigated and non-irrigated treatments, the cultivation effects on soil bulk density were very similar. The 1999 data also show that there were no noticeable differences in soil bulk density from irrigation. It indicated that a few irrigation applications during the early stage did not have any significant effects on soil bulk density. Especially, there were almost no differences beneath the topsoil (10-20 cm).

3) <u>Summary of the cultivation effects on soil bulk density</u>

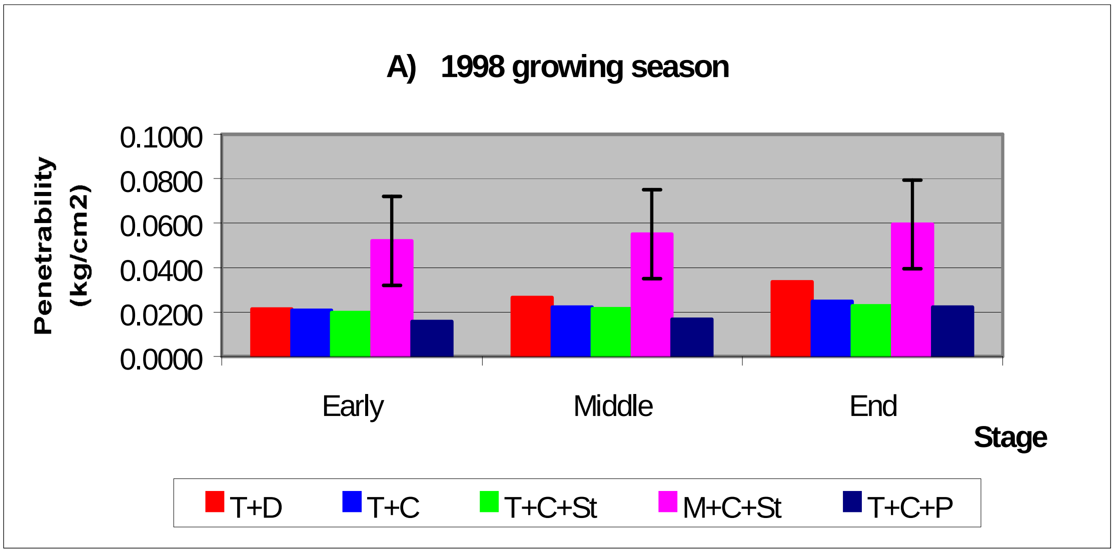
The effects of different cultivation methods on soil bulk density were very clear from two years with two cropping season measurements. Firstly, traditional intensive cultivation slightly damaged soil structure, causing soil bulk density to increase. Secondly, straw was beneficial for soil bulk density, with the decaying material helping to form good structure, leading to lower soil bulk densities after two years. Thirdly, polythene mulch protected the surface soil from raindrop impact before the canopy developed, causing lower soil bulk densities during the early and middle growth stages, but no improvement for soil structure in the longer term. Fourthly, early light irrigation did not affect soil bulk density.

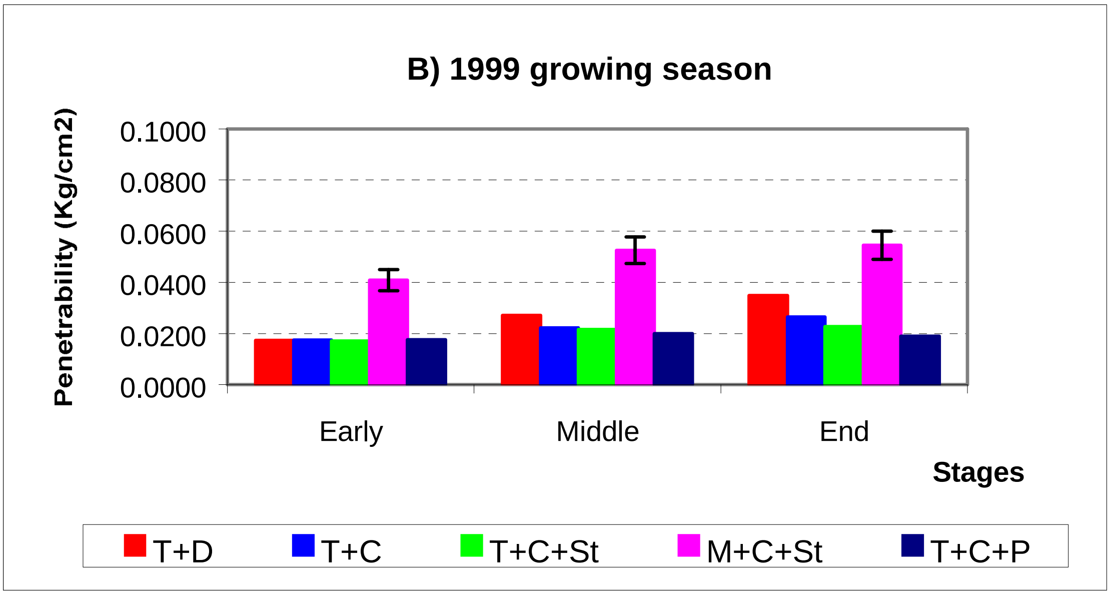
3.3.4 Effect of Cultivation Techniques on Soil Penetrability

1) Effect of cultivation techniques on soil resistance during two cropping years

Penetrometer resistance values were taken in each treatment plot in 1998 and both irrigated and non-irrigated plots in 1999 on three occasions (early, middle and end of growing seasons). The effect of cultivation on soil resistance in 1998 and 1999 are shown in Fig. 3.3.10 (A and B).

Fig 3.3.10 Cultivation effects on soil resistance during two maize growing stages in 1998 and 1999 cropping season. Values are means of three replicates, standard errors shown as vertical bars.





Based on the penetrometer reading results of 1998, cultivation treatment effects were similar in some respects to the bulk density data, although with clearer trends. Minimum tillage (M+C+St) had consistently higher crust strength than the other four treatments. The highest crust strength at the start of the season occurred on the conventionally tilled plots, while T+C+St, T+C, T+D had lower values. T+C+P treatments had the lowest values. This suggests that the effect of tillage was the main factor influencing the resistance of the surface soil. There was a significant difference between tillage and no-tillage ($n = 75$, $F = 60.38$, $P < 0.01$, $LSD_{0.05} = 0.009$). Soil compaction seems to have been prevented by the polythene. The results showed the same clear effect as for bulk density. These effects were also apparent on the straw mulch treatment. The straw had a similar function as polythene in preventing raindrop compaction.

In 1999, all treatment pits were irrigated after planting. The resistance values followed the same trend of 1998 treatments, but were noticeably lower than in 1998, especially in the early growth stage. The values were 3.3, 2.7, 12.5 and 12.6% lower than 1998 for the treatments T+D, T+C, T+C+St and M+C+St, respectively, while treatment T+C+P increased 2.7% compared with 1998. The main reasons were that cultivation and mulching affected soil structure. Secondly, early season irrigation made the soil easy to drill, but this effect occurred only in the early stage.

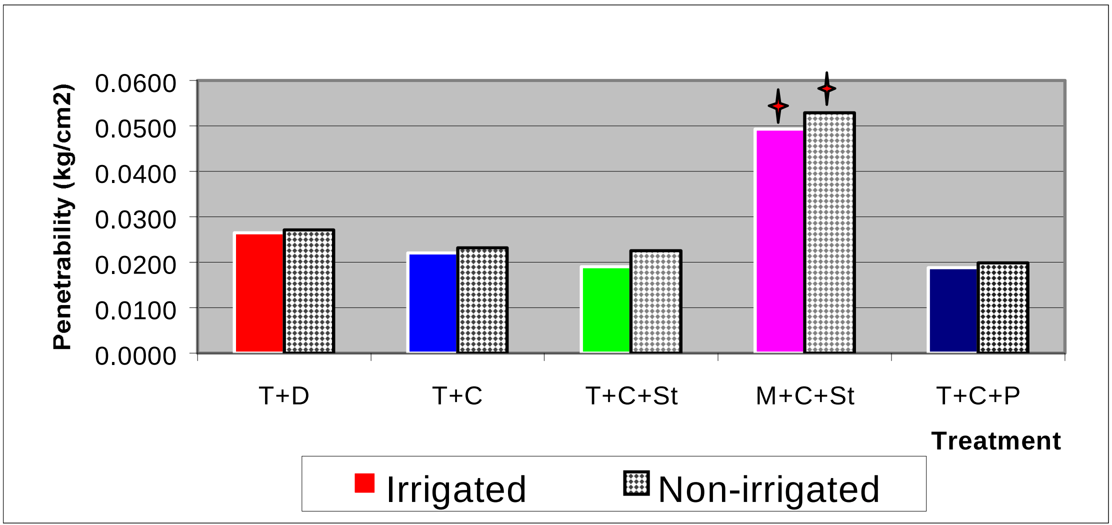
Penetrometer resistance values at the end of the season showed that there had been a marked increase on all plots, in some cases resistance more than doubling. These results can be partly attributed to raindrop impact and the movement of fines by rainsplash into inter-aggregate spaces, which would have the effect of increasing soil resistance by increasing soil packing density. However, there will also have been the effects of human disturbance (compaction), since much work was carried out on the plots in the intervening period, between the two sampling dates. Minimum tillage continued to exhibit the highest penetrometer resistance values on all plots, with a minimum increase, which must be mainly attributed to non-tillage at planting.

Comparing 1998 and 1999 values, some general effects of cultivation techniques on soil resistance were obtained. Different cultivation methods displayed different effects on surface soil resistance. Traditional cultivation combined with polythene mulch maintained a lower soil resistance during two years of experiments, while there was little increase in values in 1999. The results showed that polythene mulch cannot improve soil structure, but could maintain a lower soil resistance in the longer term. This was because polythene mulch maintained higher moisture and thus lower surface soil resistance. Straw mulch benefited decreased soil surface resistance for both traditional and minimum tillages. Penetrometer reading decreased 12.5 and 12.6% for the treatments T+C+St and M+C+St, respectively, from 1998 to 1999.

2) <u>Effect of cultivation techniques on soil resistance under irrigated and non-irrigated treatments in the 1999 cropping season</u>

Soil penetrometer reading values were strongly related to soil moisture. The experiment compared irrigated and non-irrigated treatments during the 1999 growing season. Penetrometer reading results are shown in Fig. 3.3.11.

Fig. 3.3.11 Comparison of mean penetrometer readings in irrigated and non-irrigated plots in the 1999 growing season, the differences ($p < 0.05$) were denoted by the stars.



According to the results from the two same cultivation treatment plots with different irrigation treatments, irrigation caused the soil to loosen and allowed the penetrometer cone to easily enter the surface soil. During 1999, irrigation was made twice at the early stage, with 3 litres in each pit. It also caused penetrometer readings to reduce 2.7, 4.8, 15.6, 6.8 and 5.1% for the treatments T+D, T+C, T+C+St, M+C+St and T+C+P, respectively. However, the differences for the same cultivation techniques under irrigation and non-irrigation were not significantly different. Differentiation between treatments with regard to the lowest values was indeterminate. Polythene and straw mulch tended to have low values overall, which supports the notion that the treatment offers some soil protection from direct raindrop impact. This protection minimises soil aggregate slaking and infilling of voids with fines and therefore leads to lower penetrometer resistance.

3) <u>Summary of the effect of cultivation techniques on soil penetrability</u>
Soil penetrometer readings in 1998 and 1999 show that different cultivation methods led to variations in soil resistance. During the cropping season, traditional cultivation combined with polythene mulch, maintained a lower and even soil resistance and soft structure. Under traditional cultivation, straw mulch showed very beneficial effects on improved soil structure and maintained lower soil resistance. Generally, soil resistance of traditional cultivation combined with polythene mulch treatment did not increase, while traditional cultivation plus straw mulch led to decreased soil penetrometer readings. For the minimum tillage, because of the lack of initial tillage before planting, soil resistance was significantly higher than other tillage methods. However, over two years, minimum cultivation led to decreased resistance.

3.3.5 Effect of Cultivation Techniques on Soil Chemistry

Using data on selected soil chemical properties on mixed samples from August 1997, April 1998, October 1998, April 1999 and October 1999, comparisons were made to investigate cultivation treatment effects and significant temporal changes. In 1999, there were additional samples taken at different locations in each plot. They were from the top, middle and bottom of the slope, to determine nutrient concentrations under different cultivation techniques, to examine if any nutrients had been redistributed down the plots. All these data were analysed to study if there were any significant differences. The chemical properties which were analysed were: total nitrogen, phosphorus and potassium (NPK), available nitrogen, phosphorus and potassium (NPK), soil organic matter (SOM), trace elements (B, Cu, Zn, S and Fe) and pH.

1) Effects of cultivation techniques on eight nutrients over two experiment year from 1997 to 1999

Analyses for basic soil nutrients (total nitrogen, phosphorus and potassium, available nitrogen, phosphorus and potassium, SOM and soil pH) over the period August 1997-October 1999 are shown in Table 3.3.5.

Table 3.3.5 Effects of cultivation techniques on soil Total nitrogen, phosphorus and potassium (NPK) over the period August 1997-October 1999

Element	Treatment	04/08/97	26/04/98	15/10/98	27/04/99	12/10/99
Total N (ppm)	**T+D**	380 a	260 a	530 a	520 ab	520 a
	T+C	360 a	250 a	370 a	510 a	570 ab
	T+C+St	420 a	310 a	520 a	600 ab	560 ab
	M+C+St	440 a	380 a	460 a	660 b	620 b
	T+C+P	430 a	290 a	470 a	650 ab	560 ab
Total P (ppm)	**T+D**	430 a	420 a	340 a	380 a	230 a
	T+C	430 a	480 a	230 a	380 a	230 a
	T+C+St	380 a	380 a	180 a	390 a	220 a
	M+C+St	380 a	460 a	310 a	410 a	240 a
	T+C+P	390 a	310 a	270 a	410 a	290 b
Total K (ppm)	**T+D**	37270 a	34430 a	36700 a	37370 a	32000 a
	T+C	35600 a	33430 a	33000 a	36390 a	33330 a
	T+C+St	35870 a	36130 a	37430 a	37670 a	33330 a
	M+C+St	35670 a	34130 a	34630 a	38910 a	32330 a
	T+C+P	37570 a	36870 a	3.847 a	40520 a	34670 a
Available N (ppm)	**T+D**	41.000 a	74.000 a	46.000 a	57.778 a	47.222 a
	T+C	43.000 a	75.000 a	53.667 a	70.667 a	60.444 ab
	T+C+St	40.667 a	78.000 a	51.667 a	71.000 a	62.111 b
	M+C+St	42.000 a	67.333 a	47.333 a	68.667 a	59.778 ab
	T+C+P	41.000 a	64.667 a	40.333 a	74.332 a	56.000 ab
Available P (ppm)	**T+D**	4.667 a	5.567 a	4.167 a	5.277 a	4.056 a
	T+C	4.400 a	4.533 a	4.567 a	5.700 a	5.100 ab
	T+C+St	4.125 a	4.900 a	4.533 a	5.622 a	5.200 b
	M+C+St	4.333 a	4.900 a	4.200 a	5.844 a	4.588 ab
	T+C+P	4.433 a	4.433 a	4.467 a	5.848 a	5.022 ab
Available K (ppm)	**T+D**	74.3 a	103.7 a	66.3 a	89.6 a	68.0 a
	T+C	100.0 a	110.0 a	105.0 a	137.0 a	120.3 ab
	T+C+St	94.7 a	97.0 a	120.7 a	154.3 a	152.4 bc
	M+C+St	80.0 a	104.7 a	142.0 a	174.1 a	170.0 c
	T+C+P	70.7 a	89.3 a	111.7 a	138.6 a	115.6 ab
Soil Organic matter (%)	**T+D**	0.69 a	0.47 a	0.98 a	0.95 a	0.87 ab
	T+C	0.66 a	0.45 a	0.68 a	0.94 a	0.85 a
	T+C+St	0.77 a	0.57 a	0.95 a	1.08 a	1.00 ab
	M+C+St	0.80 a	0.71 a	0.84 a	1.19 a	1.13 b
	T+C+P	0.80 a	0.53 a	0.86 a	1.18 a	0.97 ab
Soil pH	**T+D**	5.64 a	5.33 a	5.40 a	5.56 a	5.67 a
	T+C	5.67 a	5.50 a	5.77 a	5.74 a	5.71 a
	T+C+St	5.63 a	5.83 a	5.30 a	5.77 a	5.72 a
	M+C+St	5.63 a	5.50 a	5.50 a	5.51 a	5.65 a
	T+C+P	5.64 a	5.80 a	5.27 a	5.61 a	5.72 a

Table 3.3.5 illustrates the effects of cultivation techniques on main eight soil nutrients. Before cultivation treatment, the nutrients of all plots were at almost the same level. There were no significant differences between any two plots. After two years' cultivation, some marked changes were caused by different cultivation techniques. Up to 1999, SOM, total nitrogen, available N, P and K exhibited significant differences between cultivation techniques. Both traditional and minimum tillage, combined with straw mulch, led a higher nutrient contents compared with the control (T+D) (Table 3.3.6).

Table 3.3.6 Comparison of the effects of cultivation techniques before and after implementation over 1997 to 1999 experimental years

Treatment	Total N (%)	Total P (%)	Total K (%)	Available N (ppm)	Available P (ppm)	Available K (ppm)	Organic matter	pH
T+D	0.014 a	-0.020 a	-0.527 a	6.222 a	-0.611 a	-6.333 a	0.18 ab	0.03 b
T+C	0.021 ab	-0.020 a	-0.227 b	17.444 ab	0.700 bc	20.333 ab	0.19 ab	0.044 bc
T+C+St	0.026 b	-0.016 ab	-0.253 ab	21.444 b	0.975 c	57.778 b	0.23 b	0.087 c
M+C+St	0.019 ab	-0.013 ab	-0.333 ab	17.778 ab	0.254 b	90.000 c	0.33 c	0.017 a
T+C+P	0.014 a	-0.011 b	-0.290 ab	15.000 ab	0.589 bc	44.889 b	0.17 a	0.080 c

For Total N: n = 3, F = 54.785, $P < 0.001$, $LSD_{0.05}$ = 0.0058;
For Total P: n = 3, F = 68.478, $P < 0.001$, $LSD_{0.05}$ = 0.0042;
For Total K: n = 3, F = 32.698, $P < 0.001$, $LSD_{0.05}$ = -0.187;
For available N: n = 3, F = 14.523, $P < 0.005$, $LSD_{0.05}$ = 12.364;
For available P: n = 3, F = 36.985, $P < 0.001$, $LSD_{0.05}$ = 0.684;
For available K: n = 3, F = 64.785, $P < 0.001$, $LSD_{0.05}$ = 45.268;
For Organic matter: n = 3, F = 18.697, $P < 0.005$, $LSD_{0.05}$ = 0.98;
For pH: n = 3, F = 34.986, $P < 0.001$, $LSD_{0.05}$ = 0.0204.

Firstly, total nitrogen and phosphorus had significant changes between treatments. Straw mulch, combined with both traditional and minimum cultivation, had a higher increase in total nitrogen by the end of 1999, which indicated straw mulch was beneficial on soil total N. Meanwhile, traditional cultivation plus polythene mulch maintained a significantly higher total phosphorus concentration. The variation at the beginning before the two cultivations (26/04/98 and 27/04/99) was probably caused by nutrient application during winter crop planting.

Treatment with straw mulch with both traditional tillage and minimum tillage showed a significant increase of 85.7 and 35.7%, respectively, than the control. Conversely, total P and K decreased on all experimental plots, particularly the treatments of traditional cultivation (T+D and T+C) without mulch. For example, total P in both

T+D and T+C decreased by 0.020% over 2 years, while the treatment with straw mulch, T+C+St and M+C+St, decreased by 0.016 and 0.013%, respectively. Polythene mulch was efficient in reducing P loss, with a 0.011% decrease over 2 years. Total K results were more variable, especially the treatment T+D, with a decreased mean of 0.53% over 2 years. Some decreased with different mean ranges of 0.23, 0.25, 0.33 and 0.29% less for treatments T+C, T+C+St, M+C+St and T+C+P, respectively. The overall patterns indicate that losses of total P and K from these soils are more likely than N losses. They also suggest that the fertilisation programme applied in this experiment may have been unbalanced in favour of soil N, but to the detriment of soil P, under local soil acidity conditions. Treatment T+D showed very minimal increases in total N, but lost the highest rates of total P and K than the other treatments. Mulch showed the highest increases in total N, probably because mulching prevented nutrient leaching during the rainy season and decayed organic matter increased the total N content.

Secondly, some changes were caused by different cultivation techniques on available nitrogen, phosphorus and potassium. Comparing available N, P, K with total forms, the directions of change tended to be much more variable with the latter. This perhaps reflects how available N, P and K are more susceptible to change over a relatively short time span, both as a result of the imposed treatments and from regular fertiliser applications. There were very few similarities between the available and total forms of N, P and K, in terms of treatment effects. However, some interesting occurrences are noteworthy.

In terms of changes in available N, there appeared to be a consistent effect with cultivation direction and mulch on all plots. All the contour plots showed more positive effects (either greater increases or smaller decreases over the two years) than their downslope equivalents. Straw mulch had the highest increases on both the traditional tillage and minimum tillage treatments. The means were 21 and 18 ppm higher than downslope planting. Contour planting (T+C) with no mulch affected available N. The main reason was the ridge formed during contour planting caused less downslope runoff (Barton, 1999), and thus less available N loss. Polythene mulch also had increasing available N over two years, but not as pronounced as straw mulch.

This may partly be because there were no extra organic matter supplements, as there was with straw mulch. Furthermore, polythene mulch induced higher temperatures during the growing season, which caused more rapid N mineralization.

Available P tended to increase on treatments T+C, T+C+St, M+C+St and T+C+P, while on the T+D treatment it tended to decrease. This result accords with the total P changes, in that the largest decreases in total P were generally observed on treatment T+D. These results highlight the variable responses in total and available forms of P over a relatively short period and the need to assess changes in both when considering soil fertility. The highest increase in available P was observed with contour plus straw mulch, where there was an increase of 23% over the 1997-1999 period. Only T+D treatments showed a decrease in available P, by 13% compared with 1997. Thus, downslope cultivation and planting caused more available P loss. After two years, there was a significant difference between downslope treatment and the other treatments ($n = 9$, $F = 9.86$, $P < 0.05$, LSD 0.183).

In terms of changes in available K, M+C+St had the largest increase. There was a mean 90 ppm increase between 1997 and 1999. It was suggested that the more cultivation of fields the more the available K loss. The loss of available K by runoff was influenced by planting direction. The treatment T+D decreased by 6.3 ppm during this period, which probably meant more available K was removed by runoff on downslope planting. Straw mulch efficiently prevented available K being lost and had the highest increase in available K over 2 years, of 58 and 90 ppm for treatments T+C+St and M+C+St, respectively.

Thirdly, the change of soil pH value was very small, but was very important for the experimental site soil. Soil pH increased over the two years with different values under different cultivation and mulching methods. There were significantly different increases over two years. Traditional tillage, combined with straw and polythene mulch, had the greater pH unit increase. During two year period, pH values of treatments T+C+St and T+C+P increased 0.087 and 0.080 units, compared with 1997. Minimum tillage plus straw mulch showed the lowest increases during the same planting period, changing by only 0.16 units. However, the increased ranges were still significant compared with 1997. Treatments with no mulch, T+D and T+C, also had significantly increased values, with 0.030 and 0.044, respectively. Results indicated that soil structure influenced pH. Cultivation increased the soil pH value. On the other hand, the main effects could come from the application of organic manure during maize planting (1500 kg ha^{-1} manure fertiliser every year during maize planting), which could improve soil structure and lead to a neutral value (pH = 7) of soil pH.

Fourthly, SOM content increased over two years on all the treatments at different rates. The highest increases were observed on T+C+St and M+C+St, with mean increases of 0.33 and 0.23% over 3 years, respectively. The increased rates of all five treatments were significant, compared with the 1997 season. On treatments T+D, T+C and T+C+P, the increased organic content probably derived from the organic fertiliser used during crop planting. For the treatments T+C+St and M+C+St, even when the effect of organic fertiliser was eliminated, there was still clear evidence of effects coming from straw. Polythene mulch increased at a relatively lower rate than the other treatments. This was related to the soil condition under plastic inducing high temperatures, which caused rapid decomposition of organic matter, as also found in the total N content under polythene mulch.

2) <u>Comparison of cultivation treatment effects on soil nutrient movement during cropping periods</u>

The nutrient contents of soil collected from three parts (top, middle and bottom) along the slope were collected at the beginning and end of the 1999 season to investigate nutrient movement under different cultivation methods. The analytical results are presented in Table 3.3.7.

Table 3.3.7 Effects of different cultivation techniques on the distribution of soil organic matter and soil nutrients at the beginning and end of the 1999 growing season; the same letter after the mean value denotes no significance differences between the mean (p ≤0.05). Values are means of 3 blocks

	Location	Cultivation techniques									
		T+D		**T+C**		**T+C+St**		**M+C+St**		**T+C+P**	
		Beginning	End	Beginning	End	Beginning	End	Beginning	End	Beginning	End
Soil organic matter (%)	Top	0.922 a	0.770 a	0.831 a	0.728 a	1.050 a	0.952 a	1.195 a	1.056 a	1.189 a	0.940 a
	Middle	0.952 a	0.898 ab	0.934 a	0.819 ab	1.043 a	0.989 a	1.201 a	1.116 a	1.177 a	0.959 a
	Bottom	0.971 a	0.940 b	1.043 a	1.001 b	1.159 a	1.062 a	1.304 a	1.219 a	1.165 a	1.007 a
Total N (ppm)	Top	510 a	420 b	460 a	410 a	580 a	520 a	660 a	580 a	650 a	520 a
	Middle	520 a	490 ab	510 a	480 ab	570 a	540 a	660 a	610 a	650 a	530 a
	Bottom	530 a	520 a	570 a	530 b	640 a	580 a	720 a	670 a	640 a	550 a
Total P (ppm)	Top	380 a	320 a	360 a	280 a	420 a	350 a	400 a	370 a	410 a	350 a
	Middle	350 a	280 a	370 a	320 a	350 a	340 a	410 a	390 a	400 a	350 a
	Bottom	400 a	370 a	410 a	390 a	390 a	370 a	420 a	420 a	420 a	400 a
Total K (ppm)	Top	37330 a	36430 a	35330 a	34800 a	36670 a	36170 a	37370 a	36370 a	40630 a	39170 a
	Middle	37900 a	36030 a	36500 a	35100 ab	37600 a	37070 a	39000 a	37930 a	40230 a	39200 a
	Bottom	36870 a	37670 a	37330 a	35800 b	38730 a	38470 a	40370 a	39530 a	40700 a	40270 a
Available N (ppm)	Top	57.00 a	42.00 a	68.67 a	57.33 a	68.67 a	56.33 a	67.00 a	55.33 a	68.33 a	47.67 a
	Middle	60.67 a	46.67 ab	67.67 a	61.67 ab	68.67 a	60.67 a	63.00 a	57.67 a	79.00 a	50.33 a
	Bottom	55.67 a	53.00 b	76.67 a	67.33 b	74.67 a	64.33 a	76.00 a	66.33 a	80.67 a	56.67 a
Available P (ppm)	Top	4.930 a	3.67 a	5.57 a	4.77 a	5.60 a	4.53 a	5.73 a	4.30 b	5.93 a	4.60 a
	Middle	5.000 a	3.97 ab	5.60 a	5.07 ab	5.57 a	5.03 ab	5.73 a	4.55 ab	5.93 a	4.93 ab
	Bottom	5.230 a	4.53 b	5.93 a	5.47 b	5.70 a	5.73 b	6.07 a	4.91 a	6.00 a	5.53 b
Available K (ppm)	Top	85.00 a	63.67 a	154.67 ab	139.00 a	130.33 a	110.67 a	173.33 a	159.67 a	129.33 a	106.00 a
	Middle	92.33 a	68.33 a	147.00 a	150.67 a	132.00 ab	116.33 a	169.00 ab	171.00 a	131.67 a	113.67 a
	Bottom	91.33 a	72.00 a	161.33 b	167.67 a	148.67 b	134.00 a	180.00 b	179.33 a	154.67 a	127.00 a

Based on the comparison of seven treatments, organic matter, total NPK and available NPK, some effects of planting direction and mulching methods could be observed. Compared with the beginning and the end of the growing season, downslope cultivation caused significant movement of SOM, total N, available N and available P from the top to bottom of the slope. This movement of elements were probably mainly due to runoff. Straw mulch had noticeable effects of maintaining a higher mean nutrient concentration on the slope. Comparing the contour planting with mulch and no-mulch treatments, no-mulch treatments had significant changes in SOM, total N, total K, available N and available K between the beginning and end of the season. Traditional cultivation plus straw mulch treated plots had significant changes, but just in available P during the same period. It is suggested that intensive cultivation also caused higher nutrient movement when there was no covering materials. Both minimum tillage, combined with straw mulch and traditional tillage plus polythene mulch, had similar effects of maintaining nutrients at a consistent mean level along each slope. Both of these treatment methods only had one element (available P), which was significantly different between the beginning and the end of the season.

3) Other analysed nutrients

Besides the eight main nutrients, other nutrients, which might influence crop growth, including CaO, Fe_2O_3, K_2O, MgO, P_2O_5, Cu, Mn, S and Zn, were analysed. The results are presented in Table 3.3.8.

Table 3.3.8 Effect of different cultivation techniques on soil nutrients between August 1997 and October 1999
The same letter after the mean value denotes no significance differences between the mean (p ≤0.05). Values are means of 3 blocks

Year	Treatment	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Fe_2O_3 (%)	K_2O (%)	MgO (%)	P_2O_5 (%)	Cu (ppm)	Mn (ppm)	S (ppm)	Zn (ppm)
1997 (mean)	**T+D**	16.176 a	62.004 a	0.3162 a	7.2560 a	1.9693 a	0.5940 a	0.1126 a	61.1 a	576.9 a	32.8 a	28.6a
	T+C	16.441 a	61.405 a	0.4418 a	7.4833 a	2.0512 a	0.6739 a	0.0795 a	53.8 a	711.8 a	63.4 a	29.7 a
	T+C+St	16.850 a	58.953 a	0.3542 a	7.5738 a	2.1034 a	0.6245 a	0.1218 a	50.6 a	679.3 a	62.0 a	28.2 a
	M+C+St	16.704 a	55.934 a	0.3907 a	8.4509 a	2.1021 a	0.6129 a	0.1176 a	58.1 a	771.8 a	114.7 a	31.2 a
	T+C+P	16.000 a	61.215 a	0.3237 a	7.0422 a	2.4538 a	0.6081 a	0.1092 a	48.7 a	639.5 a	52.5 a	30.4 a
1999 (mean)	**T+D**	16.525 ab	64.936 a	0.3741 a	6.9130 a	2.0015 a	0.6382 a	0.1094 a	48.0 a	448.4 a	143.1 a	26.6 ab
	T+C	15.384 ab	64.037 ab	0.5949 a	6.7785 a	1.9419 a	0.6569 a	0.1035 a	46.3 a	566.0 ab	90.5 a	24.3 a
	T+C+St	16.660 a	62.140 ab	0.3466 a	6.5044 a	1.8257 a	0.6231 a	0.1167 a	49.5 a	585.9 ab	149.6 a	28.2 ab
	M+C+St	14.978 b	54.690 b	0.3709 a	8.1376 a	1.9791 a	0.5250 a	0.1057 a	57.4 a	750.6 b	137.9 a	32.0 ab
	T+C+P	15.714 ab	59.280 ab	0.3313 a	6.7887 a	2.1006 a	0.5579 a	0.1105 a	52.6 a	689.4 ab	98.1 a	32.4 b
Difference of 1999 vs. 1997	**T+D**	0.349	2.932	0.0579*	-0.3431	0.0322	0.0443	-0.0033	-13.1***	-128.5**	110.3***	-1.9*
	T+C	-1.058	2.632	0.1532*	-0.7048*	-0.1093	-0.0170	0.0239	-7.5*	-145.8***	27.1*	-5.4**
	T+C+St	-0.191	3.187	-0.0076	-1.0694***	-0.2777	-0.0014	-0.0051	-1.1	-93.3*	87.6***	0.0
	M+C+St	-1.726	-1.244	-0.0198	-0.3133	-0.1230	-0.0879*	-0.0119	-0.7	-21.3	23.2*	0.7
	T+C+P	-0.286	-1.936	0.0076	-0.2535	-0.3532	-0.0502*	0.0013	4.0*	49.9*	45.6*	1.9*

In which: "*" indicates the difference in the same treatment over the period August 1997 to October 1999.
"*"- P<0.05 ; "**"- P<0.01; "***"- P<0.001.

The results of different cultivation techniques showed that CaO, Fe_2O_3, K_2O, MgO, P_2O_5, Cu and S did not significantly differ between treatments over two cropping years. The contents in different cultivation techniques did not exhibit significant differences during the two years. At the end of the 1999 cropping season, Mn and Zn displayed significant differences between treatments. Minimum tillage combined with straw mulch had a higher Mn content than other treatments. Both M+C+St and T+C+P had higher Zn concentrations than other cultivation techniques.

Some compounds, such as Al_2O_3 and SiO_2 were analysed. Although they are not nutrients, they affect soil structure, which indirectly influences nutrient absorbion. For example, abundant aluminumisation is the typical character of Yunnan upland soil, which causes tight fixing of phosphate and leads to lower P fertiliser efficiency (Xu Xiangyi, 1993). After different tillage and planting treatments over a long time, both compounds would change, which can help to understand the changed structure. The results showed that Al_2O_3 noticeably changed on T+C and M+C+St. SiO_2 displayed significant differences between treatments over two years.

The changing concentrations of nutrients on the same treatment were compared during the two experimental years. There were significant decreases of CaO on T+D and T+C, which indicated cultivation helped decrease CaO concentrations. Contour cultivation with straw mulch had the highest ability to decease Fe_2O_3. Minimum tillage also significantly decreased MgO. Straw mulch efficiently prevented Cu loss. S increased significantly on all treatments. This may have been due to the organic fertilizer used during cropping seasons. Mn decreased on T+D, T+D, T+C+St and increased on the treatment T+C+P. It seems related to the runoff and the higher temperature for polythene treated areas. Zn significantly decreased on T+D and T+C, but increased on T+C+P, while there were no changes on straw mulch treatments.

5) <u>Summary of the effects of cultivation techniques on soil nutrients during two experimental years</u>

Soil nutrients were affected by cultivation methods, planting direction and mulching methods. This is based on analyses of the main nutrient parameters (SOM, total NPK, available NPK and pH). Other nutrients (CaO, Fe_2O_3, K_2O, MgO, P_2O_5, Cu and S) also changed over the period from August 1997 to October 1999 and between the beginning and end of the planting season during 1999.

Straw and polythene mulch efficiently prevented nutrients being washed away by runoff and maintained an even nutrition level along the slope during the rainfall season. The decayed straw was beneficial for increasing SOM and total and available nitrogen, which improved soil structure and increased soil pH. Minimum tillage had some special effects on soil structure because of less disruption of soil structure by tillage procedures. This was beneficial for the nutrient retention in the soil, but not good for pH improvement. Contour planting was more effective for maintaining nutrients than downslope planting.

3.3.6 Effect of Cultivation Treatment Techniques on Soil Particle Size Distribution

1) The general change in conditions during the 1998 to 1999 crop periods

To assess the most suitable single measurement which could be used to initially compare particle size distributions between samples taken in 1997 and 1999, the sample median and mean values (as determined by the Laser Granulometer) on each set were compared (Table 3.3.9).

Table 3.3.9 Change in mean soil particle distribution between August 1997 and October 1999 (n = 15) (%)

Treatment	1997 year			1999 year		
	Clay	Silt	Sand	Clay	Silt	Sand
T+D	19.84 a	52.83 a	27.34 a	21.34 a	52.38 a	26.28 a
T+C	21.01 a	54.13 a	24.86 a	22.51 a	53.91 a	23.58 a
T+C+St	20.47 a	53.45 a	26.08 a	23.25 a	51.66 a	25.09 a
M+C+St	22.49 a	54.94 a	22.57 a	22.09 a	54.12 a	23.79 a
T+C+P	20.22 a	52.98 a	26.80 a	22.34 a	53.64 a	24.02 a

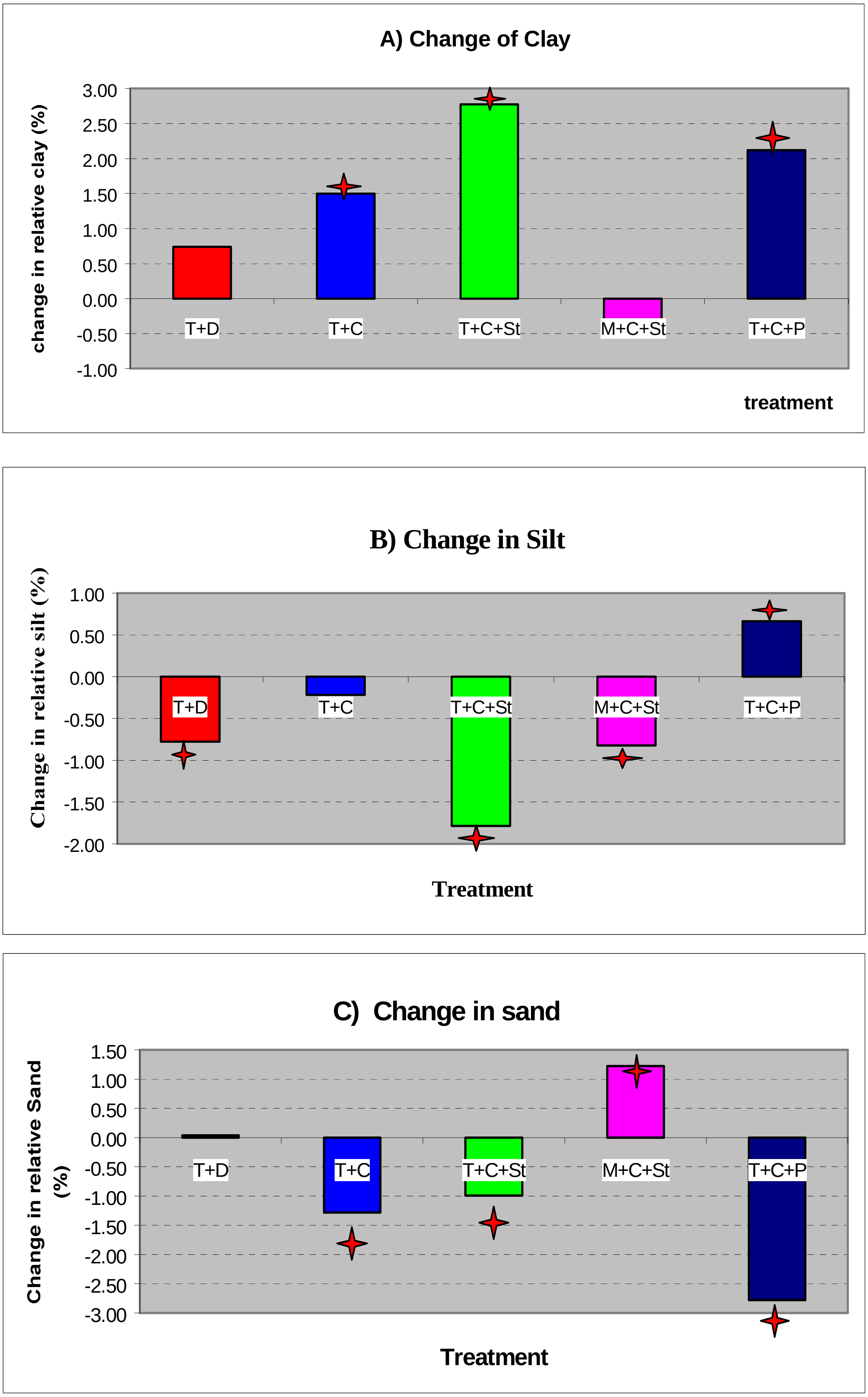
Based on the results, clay was ~20-25% of the soil mass, while silt and sand was 50% and 25%. According to the FAO classification, the results indicate that the plot soils were silt loams. After two years of treatment, using different cultivation and planting directions combined with mulching methods, some soil characteristics were improved. Although treatment effects were not clear and there were no significant differences between any two treatments, the data did show some interesting features. The comparison of mean value of median soil particle size in August 1997 and October 1999 are presented in Table 3.3.10.

Table 3.3.10 Comparison of mean value (*μm*) of median soil particle size in August 1997 and October 1999

Treatment	1997 year	1999 year
T+D	12.56	13.19
T+C	12.31	12.38
T+C+St	12.65	12.09
M+C+St	13.17	12.15
T+C+P	12.10	13.19

There were some changes in the median soil particle sizes over two years. But using t-tests no significant differences were found between 1997 and 1999. Treatment T+C+St and M+C+St had decreased median values, while T+D and T+C+P treatments had increased values. Results indicated that contour cultivation positively affected soil median particle size, for contour planting retained more fines on the plots. To further investigate particle size distributions, differences in the relative percentages of sand, silt and clay in the soil between the two years were determined for each plot (Figs. 3.3.12 A, B and C).

Fig. 3.3.12 Effects of cultivation techniques on soil particle size distribution between August 1997 and October 1999. (A- Clay, B - silt, C - sand)



The results clearly show the general trend of relative proportions of sand and silt decreased, while clay increased. This substantiates the data on median particle size and confirms the notion that the soil did tend to become relatively finer with time.

The largest decrease in sand content was observed on conventional tillage combined with polythene, followed by contour planting and straw mulch. Polythene mulch had the highest decrease in sand content. Treatments T+D and M+C+St exhibited an increase in relative sand content, particularly minimum tillage with straw mulch. Generally, contour planting significantly increased clay content during the two years, especially on polythene mulch, where there was a 2.12% increase after two cultivation seasons. Downslope planting produced an easy condition for fine particles to be washed away, which caused sand to increase. Considering the silt content, the smallest decrease in silt was observed with contour planting, and with polythene mulch, the treatment exhibited a small increase, while the remaining treatments all showed decreases. Straw mulch treatment had a higher decrease in silt with 0.78% decrease during August 1997 to October 1999. Such changes in particle size could be related to erosion rates, where silts are preferentially removed, although this hypothesis requires further study and verification. It also appears that straw has the ability to protect fines from being washed away by runoff. These results are related to the increase in sand (the main constituent of SiO_2) discussed in Chapter 3.3.5.

3.4 Measurement of Maize Crop Development

Many factors influence crop development, including soil, climate, crop varieties and cultivation management. In any one location, after selecting a variety, the cultivation techniques and crop management practises will have major influences on crop productivity, modified by the interactions with the weather during the growing season. In this section, the effects of the different cultivation techniques on crop development are investigated.

3.4.1 Effects of cultivation techniques on plant height

1) Effects of cultivation treatment techniques on plant height during 1998 and 1999

Maize plant height under different cultivation techniques was measured at different stages at seven times in both 1998 and 1999. The results are shown in Table 3.4.1.

Table 3.4.1 Effects of cultivation techniques on plant height measured at different days after sowing (d). The data have been analysed by repeat ANOVA with significant differences (P ≤0.05) denoted by different letters. The values are the means of the 3 blocks for each treatment

	Treatment	Plant height (cm)						
		45d	**60d**	**75d**	**90d**	**105d**	**120d**	**135d**
1998	T+D	71.8 a	109.2 a	142.3 a	184.0 a	191.0 a	190.5 a	190.5 a
	T+C	70.4 a	113.9 a	149.4 a	180.1 a	196.8 a	188.5 a	188.5 a
	T+C+St	68.6 a	104.9 a	139.9 a	170.2 a	189.6 a	191.1 a	191.1 a
	M+C+St	68.0 a	103.7 a	143.1 a	182.6 a	190.9 a	192.3 a	192.3 a
	T+C+P	90.9 b	136.3 b	162.4 b	189.6 a	211.4 a	210.6 a	210.6 a
1999		**40d**	**55d**	**70d**	**85d**	**100d**	**115d**	**130d**
	T+D	64.4 a	75.2 a	187.0 a	187.1 a	187.4 a	187.5 a	187.5 a
	T+C	64.2 a	75.3 a	186.9 a	191.9 a	192.0 a	192.2 a	192.2 a
	T+C+St	70.8 a	84.8 a	196.5 a	197.5 a	197.3 a	199.8 a	199.8 a
	M+C+St	68.0 a	77.6 a	192.4 a	192.6 a	193.3 a	196.9 a	196.9 a
	T+C+P	97.7 b	120.5 b	214.7 b	214.7 b	215.2 b	215.9 a	215.9 a

The growth trends in 1998 and 1999 were similar. Contour cultivation, combined with polythene mulch, produced significant increases in plant height in both years. The significant difference occurred at the early and middle maize growth stages. In 1998, the first three measurement occasions (45, 60 and 75 days after sowing) showed significant differences between cultivation techniques. Contour planting combined with polythene mulch exhibited quicker growth than other cultivation methods, but this effect reduced with time after sowing. For example, at the time of 45 days after sowing, T+C+P treatment had a greater height by 26.6, 29.1, 32.5 and 33.7% than treatments T+D, T+C, T+C+St and M+C+St, respectively (n = 8, F = 68.453, P <0.001, $LSD_{0.05}$ = 14.3). At 60 days after sowing, T+C+P was 24.8, 19.7, 29.9 and 31.4% higher than T+D, T+C, T+C+St and M+C+St, respectively (n = 8, F = 45.687, P <0.001, $LSD_{0.05}$ = 21.5). At 75 days after sowing, treatment T+C+P was just 14.1, 8.7, 16.1 and 13.5% higher than T+D, T+C, T+C+St and M+C+St, respectively (n = 8, F = 68.453, P <0.001, $LSD_{0.05}$ = 10.8). The last four measurements (90, 105, 120 and 135 day after sowing) were not significantly different.

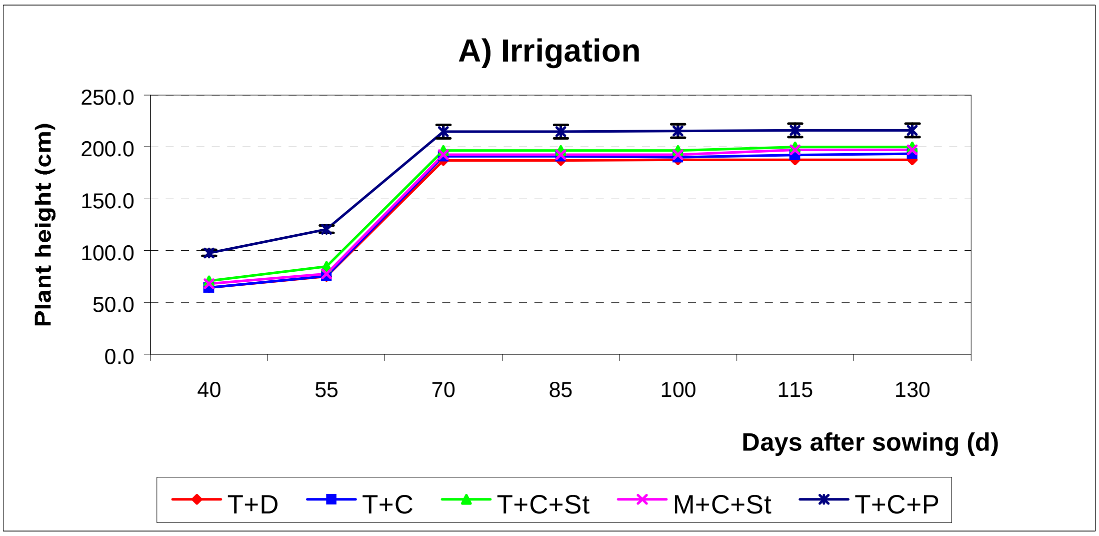
Similar trends in maize growth were observed in the 1999 cropping season. Because of irrigation when planting, the mulch materials (polythene and straw) were put on after irrigation and soil condition was changed compared with 1998 during the early growth stages. Different cultivation techniques showed significant differences at five measurement times out of the total of seven measurement occasions. Contour cultivation combined with polythene mulch showed significant increases on five measurement occasions (40, 55, 70, 85 and 100 days after sowing). The effects between cultivation techniques were higher than in 1998. For example, by 40 days after sowing, T+C+P had a greater mean plant height of 51.7, 52.2, 40.0 and 43.7% than T+D, T+C, T+C+St and M+C+St, respectively ($n = 8$, $F = 75.312$, $P <0.001$, $LSD_{0.05} = 24.3$). At 55 days after sowing, they were 60.2, 60.0, 42.1 and 55.3% higher, respectively ($n = 8$, $F = 24.367$, $P <0.001$, $LSD_{0.05} = 30.1$). At 70 days after sowing, they were 51.9, 39.1, 31.5 and 40.1% higher, respectively ($n = 8$, $F = 13.245$, $P <0.001$, $LSD_{0.05} = 15.7$). At 85 days after sowing, they were 17.2, 15.2, 12.3 and 11.5% higher, respectively ($n = 8$, $F = 14.356$, $P <0.001$, $LSD_{0.05} = 15.3$). Even at 100 day after sowing, T+C+P still had greater plant heights by 16.1, 12.1, 11.9 and 13.1% than T+D, T+C, T+C+St and M+C+St, respectively ($n = 8$, $F = 68.453$, $P <0.001$, $LSD_{0.05} = 15.7$).

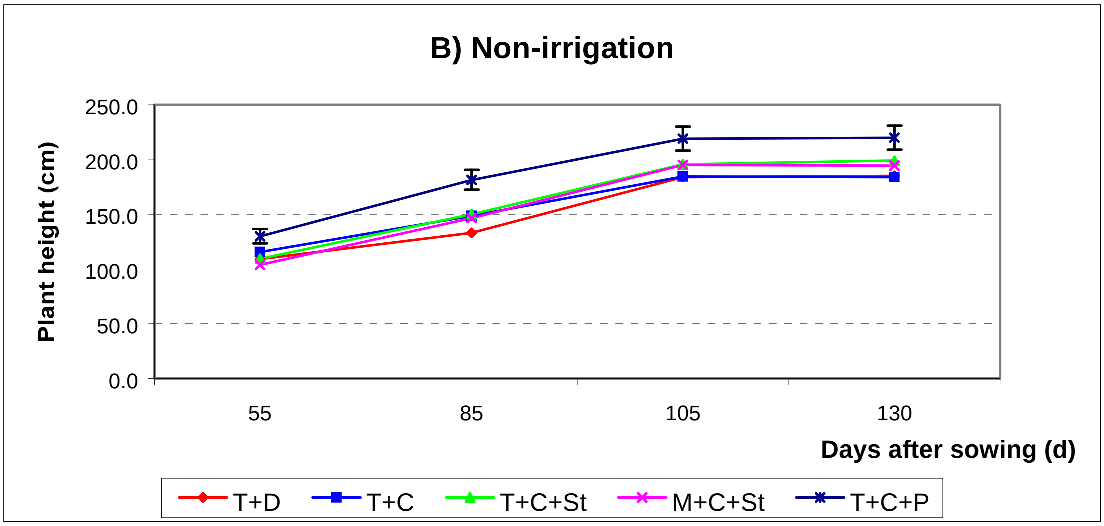
Straw mulch had some benefit for crop growth when the weather was dry. In 1999, the rainfall in July was 128.3 mm lower than 1998 (209.4 mm). This dry weather caused the maize leaf to show signs of stress. Treatment T+C+St had 12.8 and 12.6% greater plant heights than T+D and T+C, respectively (55 days after sowing).

2) <u>Effect of cultivation techniques on plant height under irrigated and non-irrigated conditions in 1999</u>

The effects of different cultivation methods on maize growth were investigated in two different experiments with the same treatments, but one without irrigation and the other with irrigation at planting time and early growth stages in 1999. The effects of cultivation techniques for these two irrigation methods are compared in Fig. 3.4.1 (A and B).

Fig. 3.4.1 Effect of cultivation techniques on plant height under irrigation (A) and non-irrigation (B)





Comparing the growth trends of two experiments, the effects of different cultivation techniques were very clear. Contour cultivation combined with polythene showed significantly higher growth under both irrigation and non-irrigation. Maize under early irrigation grew more quickly than non-irrigation, up to the top height of the maize after 70 days, forming a larger canopy. The plants under non-irrigation treatments took longer to reach the same height as irrigated plants.

3.4.2 Effects of cultivation techniques on Green Leaf Area Index and Green Leaf Area Duration

In this section, the changed trends of Green Leaf Area Index (GLAI) and Green Leaf Area Duration (GLAD) under different cultivation techniques in the 1998 and 1999 cropping seasons, as well as the relationship with other factors, are presented.

1) <u>Effects of cultivation techniques on GLAI during the growing season in 1998 and 1999</u>

The measured results of Green Leaf Area Index at different days after sowing are shown in Table 3.4.2.

Table 3.4.2 Effects of cultivation techniques on GLAI measured at different days after sowing (d). The data have been analysed by repeat ANOVA with significant differences (P ≤0.05) denoted by different letters. The values are the means of the 3 blocks for each treatment

Time		Green Leaf Area Index						
		45d	**60d**	**75d**	**90d**	**105d**	**120d**	**135d**
1998	**T+D**	0.23 a	1.05 a	1.90 a	2.75 ab	2.83 a	2.36 a	1.62 a
	T+C	0.25 a	1.12 a	1.97 a	2.82 ab	2.93 a	2.65 ab	1.81 a
	T+C+St	0.23 a	1.06 a	1.86 a	2.66 a	2.69 a	2.45 ab	1.68 a
	M+C+St	0.25 a	0.87 a	1.79 a	2.72 ab	2.69 a	2.34 a	1.39 a
	T+C+P	0.42 b	1.52 b	2.35 b	3.18 b	3.19 a	2.94 b	2.04 b
1999		**40d**	**55d**	**70d**	**85d**	**100d**	**115d**	**130d**
	T+D	0.31 a	0.86 a	1.06 a	1.89 a	1.83 a	1.72 a	0.60 a
	T+C	0.32 a	1.12 ab	1.23 a	2.09 ab	1.97 ab	1.77 a	0.54 a
	T+C+St	0.37 a	1.21 bc	1.37 a	2.19 b	2.26 b	2.08 ab	0.68 a
	M+C+St	0.29 a	0.93 ab	1.23 a	2.11 b	2.06 ab	1.80 a	0.79 a
	T+C+P	0.87 b	1.49 c	2.63 b	3.15 c	3.05 c	2.34 b	0.82 a

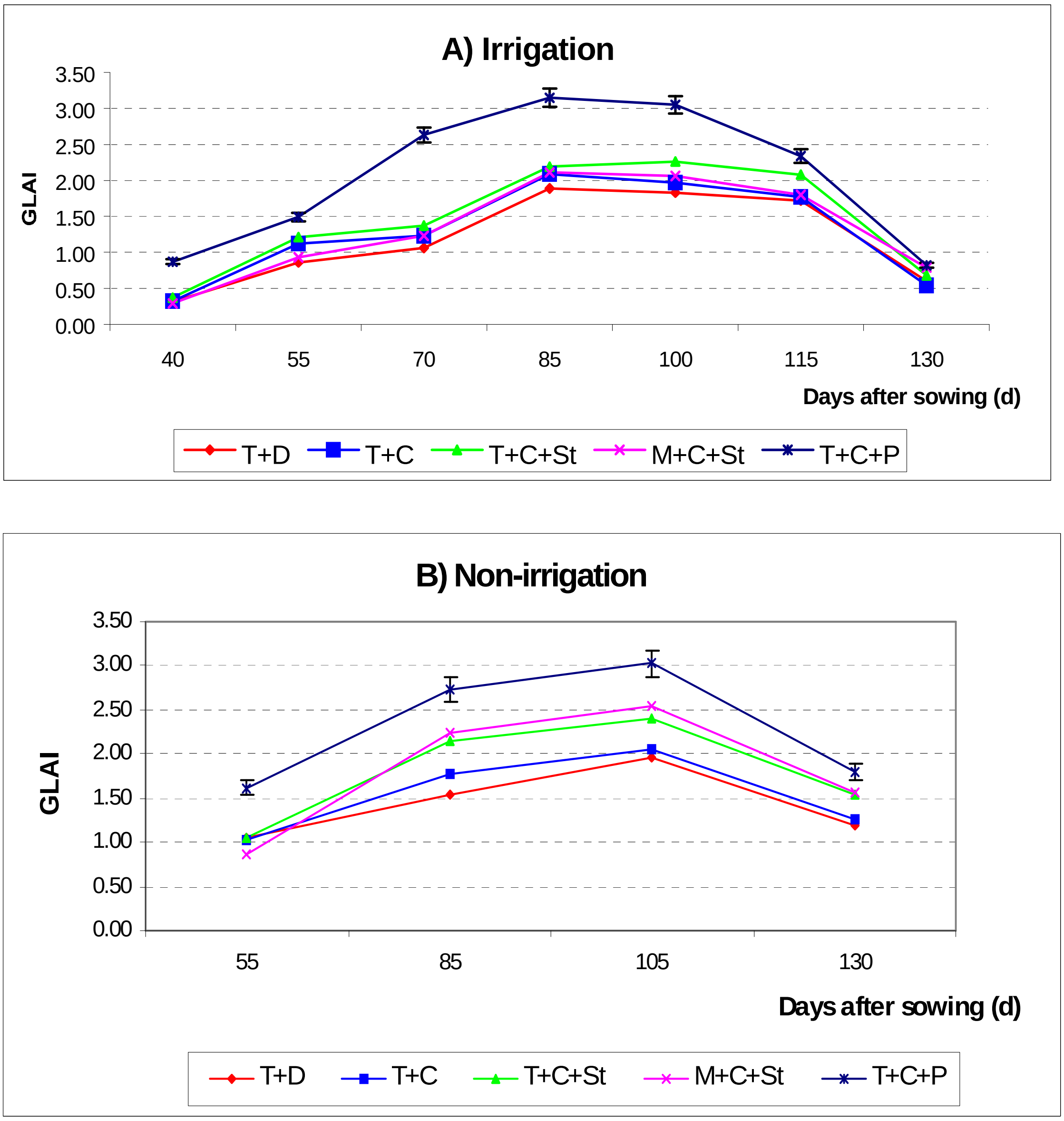
From the results presented in Table 3.4.2, the effects of different cultivation techniques are clear. In 1998, the effects of different cultivation techniques on GLAI showed significant differences between treatments. According to the analysis, contour cultivation combined with polythene mulch exhibited significantly higher Green Leaf Area Index at six measurement occasions within a total of seven. The cultivation effects on GLAI were higher at the early than middle and then later growth stages. At 45 days after sowing, contour cultivation treatment (T+C+P) had 80.7, 69.6, 80.5 and 69.8% higher GLAI than T+D, T+C, T+C+St and M+C+St treatments, respectively (n = 3, F =13.477, P <0.01, $LSD_{0.05}$ = 0.06). With time, the differences became less but were still significant. For example, at 60 days after sowing, T+C+P had 44.7, 35.7, 43.4 and 74.7% higher GLAI than T+D, T+C, T+C+St and M+C+St, respectively (n = 3, F = 14.354, P <0.01, $LSD_{0.05}$ = 0.25). Even up to 120 days after sowing, T+C+P still had significantly higher GLAI with 24.4, 10.9, 20.1 and 25.2% more than T+D, T+C, T+C+St and M+C+St, respectively (n = 3, F = 13.972, P <0.01, $LSD_{0.05}$ = 0.17). Effects between other cultivation techniques (T+D, T+C, T+C+St and M+C+St) did not show any significant differences during the growing season.

In 1999, GLAI values exhibited greater differences than 1998. Irrigation was implemented at the time of maize planting. Under this situation, contour cultivation plus polythene mulch showed much greater benefits on canopy development. There were six measurements showing significant differences in GLAI, compared with other cultivation techniques during early and middle growth stages (at 40 days: n = 3, F = 25.346, P <0.01, $LSD_{0.05}$ = 0.27; at 55 days: n = 3, F = 15.104, P <0.01, $LSD_{0.05}$ = 0.31; at 70 days: n = 3, F = 25.346, P <0.01, $LSD_{0.05}$ = 1.18; at 85 days: n = 3, F = 19.867, P <0.01, $LSD_{0.05}$ = 0.86; at 100 days: n = 3, F = 11.326, P <0.01, $LSD_{0.05}$ = 0.41; at 115 days: n = 3, F = 8.347, P <0.05, $LSD_{0.05}$ = 0.42). Straw mulch also showed noticeable benefits for GLAI on three occasions (55, 85 and 100 days after sowing). Both T+C+St and M+C+St treatments showed significantly higher GLAI than the control (T+D). T+C+St had significantly higher GLAI, with 15.9 and 23.5% more than control at 85 and 100 days after sowing, respectively. For M+C+St GLAI was significantly higher by 11.6 and 12.6% more than the control treatment at 85 and 100 days after sowing, respectively.

2) <u>Effects of cultivation techniques on GLAI in irrigation and non-irrigation experiments in 1999</u>

In 1999, the same cultivation techniques were compared in two experiments, one with irrigation and one without. There were seven measurements of GLAI in the irrigation plots and four measurements in the non-irrigation plots. The general changes of GLAI are compared in Fig. 3.4.2 (A- irrigation and B- non-irrigation).

Fig. 3.4.2 Effects of cultivation techniques on maize GLAI under irrigation (A) and non-irrigation (B)

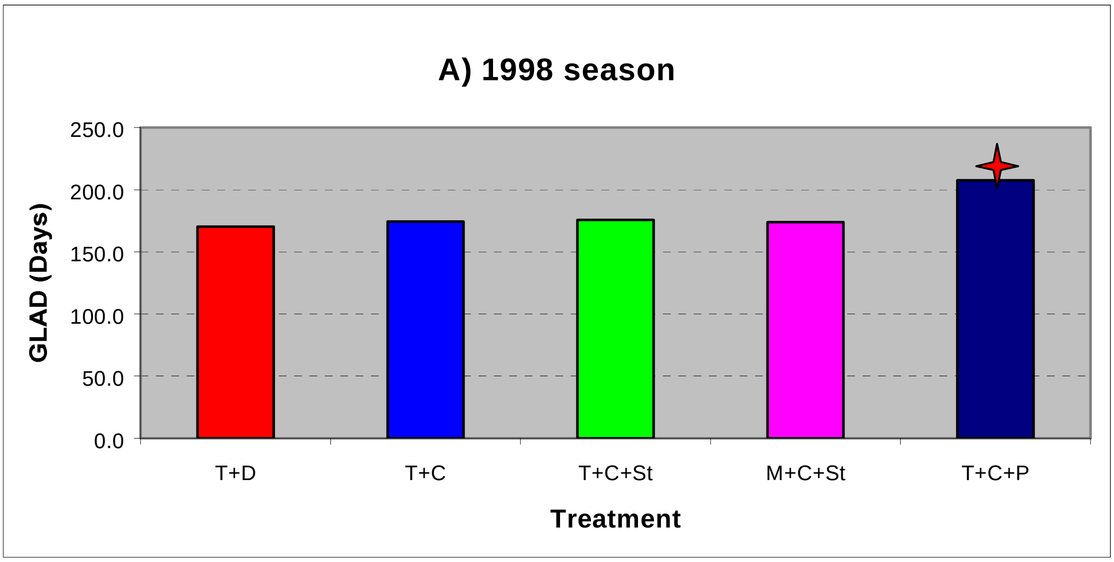


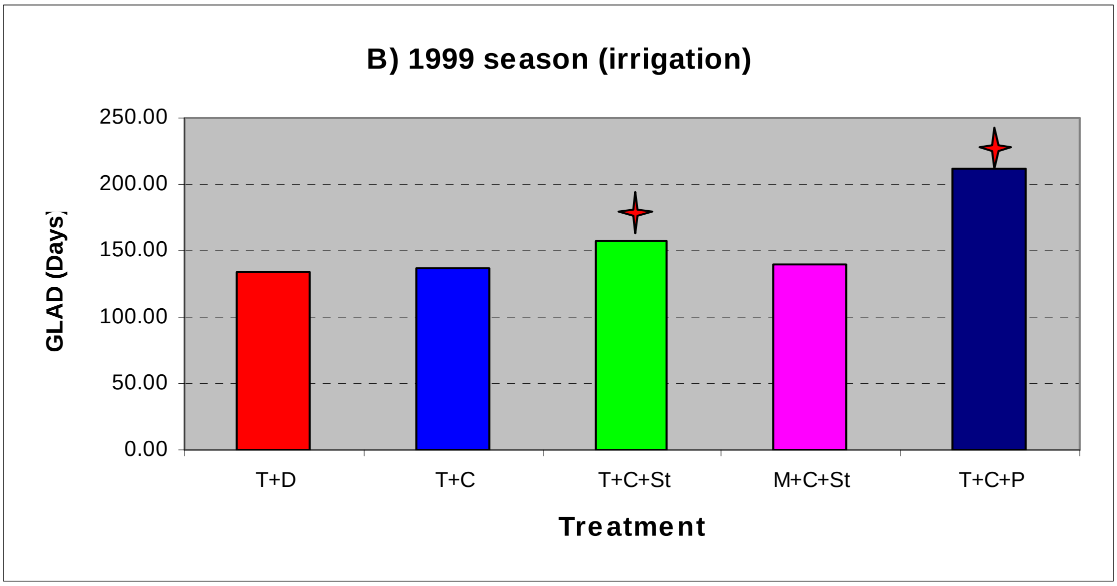
From the results, it was clear that the trends in GLAI change under the different irrigation regimes for the different cultivation techniques were different. Under irrigation at planting time and for most of the season, there were significant differences between T+C+P and the other four treatments. Under non-irrigation, GLAI showed more differences between cultivation methods. Besides the T+C+P, straw mulch combined with both contour cultivation and minimum tillage exhibited significantly higher GLAI on two occasions (at 85 days: n = 3, F = 13.378, P <0.01, $LSD_{0.05}$ = 0.195; at 105 days: n = 3, F = 15.010, P <0.01, $LSD_{0.05}$ = 0.130). These indicated that straw mulch was beneficial for increasing maize green leaf area when it was dry during early growth stages.

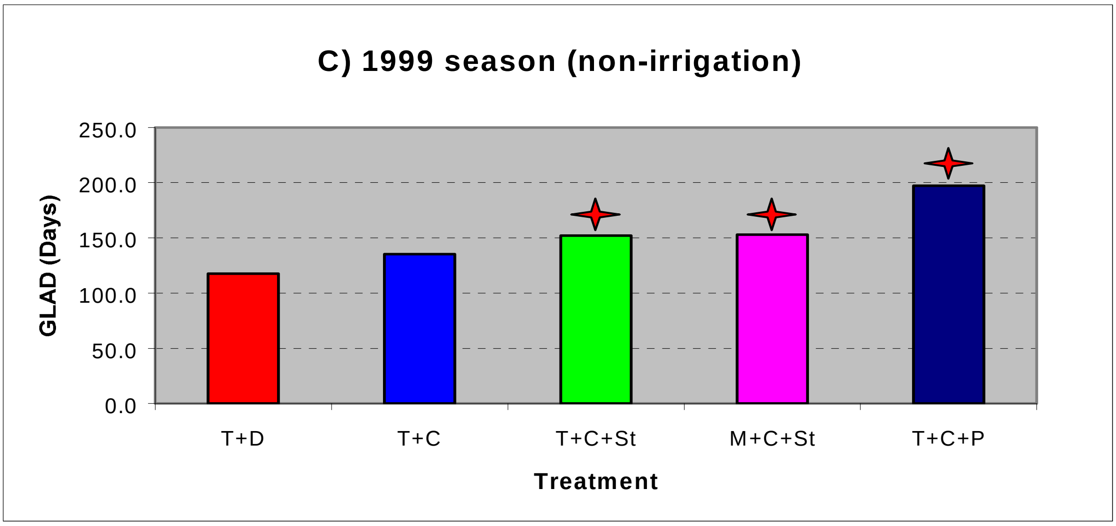
3) <u>Effects of cultivation techniques on maize GLAD during the 1998 and 1999 cropping seasons</u>

Effects of different cultivation techniques on maize GLAD of 1998 and 1999 were calculated according to the GLAI curves in each plot. The results were analysed by ANOVA and LSD, as shown in Fig. 3.4.3 (A, B and C).

Fig. 3.4.3 Effects of cultivation techniques on maize GLAD during 1998 and 1999 cropping seasons (A: 1998, B: 1999 under irrigation and C: 1999 under non-irrigation), the star symbol indicates significant differences (P ≤0.05)







GLAD results accorded with GLAI, as expected. There were significant differences between cultivation techniques, both in 1998 and 1999. In 1998, when there was no irrigation at planting and during the early season, contour cultivation combined with polythene mulch had significantly higher GLAD than the other treatments ($n = 3$, $F = 38.38$, $P < 0.001$, $LSD_{0.05} = 28.6$ days). They were 37.4, 25.0, 45.1 and 40.4 days longer than treatments T+D, T+C, T+C+St, M+C+St, respectively.

In 1999, T+C+P under both irrigation and non-irrigation exhibited similar trends with a significantly higher GLAD than the other cultivation methods. Under irrigation, T+C+P had 77, 74, 53 and 71 days longer than T+D, T+C, T+C+St and M+C+St, respectively ($n = 3$, $F = 12.14$, $P < 0.01$, $LSD_{0.05} = 20.31$). Contour cultivation with straw mulch (T+C+St) also exhibited significantly higher GLAD, with 30 days more than the control (T+D). It seems that, under irrigation, straw mulch was also beneficial, but to a lesser extent than polythene mulch.

Under non-irrigation, similar trends were obtained, but the effects of straw mulch were more marked. T+C+P showed significantly higher GLAD than the other four cultivation techniques ($n = 3$, $F = 17.14$, $P < 0.01$, $LSD_{0.05} = 14.4$). Both T+C+St and M+C+St exhibited significantly higher GLAD with 29 and 33 days more than the control (T+D). There were no significant differences between T+D and T+C. This confirmed that the effects of cultivation with mulches (both straw and polythene) were very beneficial for the increase in maize Green Leaf Area Duration.

4) The relationship between GLAI and other factors

From the results of GLAI measurements under different cultivation methods, it was clear that GLAI was influenced by many factors, including weather, soil conditions, management (planting direction, mulch material, irrigation) and plant height. In this section, some of these inter-relationships are analysed.

A) Relationship between GLAI and soil moisture and temperature under different cultivation techniques in 1998 and 1999

Soil moisture varies with time and season. In 1998, correlation was less noticeable because of no irrigation at maize planting. When water was supplied during sowing, there were significant relationships between GLAI and soil moisture at the seedling stage. For example, in 1999, GLAI had significant correlation coefficients with soil moisture at different soil depths at 55 days after sowing. The correlation coefficients were very significant under different soil depths with 0.893**, 0.896** and 0.987*** on 40 days, and 0.902**, 0.839** and 0.889** on 55 days, at the depth of 0-5, 5-10 and 10-15 cm, respectively ($n = 8$). As the season progressed and rainfall increased, water became less limiting and the correlation was no longer significant (here "*" means correlation is significant at the $P < 0.05$ level; "**" means correlation is highly significant at P the < 0.01 level; and "***" means correlation is highly significant at the $P < 0.001$ level).

As one of the most important factors affecting maize growth, temperature remarkably affected the increase in Green Leaf Area during the early growth stage, based on the correlations between GLAI and soil temperature during both the 1998 and 1999 seasons. A higher soil temperature, in a certain range, is useful for germination and seedling growth. The surface soil temperature had very significant correlation coefficients with maize leaf development. In 1998, based on methods of planting direction and mulching, the correlation coefficients between soil temperature and GLAI, on 40 days after sowing, were 0.953***, 0.988***, 0.992**, 0.994***, 0.984*** and 0.937*** ($n = 8$) for 0, 5, 10, 15 and 20 cm soil depths, respectively. The effect decreased with increasing days after sowing.

In 1999, a similar effect of temperature on GLAI was found, at 40 days after sowing. The correlation coefficients between soil temperature and GLAI were 0.920**, 0.975***, 0.986***, 0.981*** and 0.966*** at 0, 5, 10, 15 and 20 cm soil depths (n = 8). Afterwards, soil temperature still had positive relationships with GLAI, but with a decreasing trend. By 85 days after sowing, the relationship was very weak.

B) Relationship between GLAI and plant components under different cultivation techniques in 1998 and 1999

In addition to these factors, GLAI also had a strong correlation with other growth parameters, such as plant leaf number and plant height. In 1998, the correlation coefficients were highly significant at P <0.01 for GLAI with leaf number with r = 0.998***, 0.983***, 0.973***, 0.988*** and 0.977*** (n = 8), for treatments T+D, T+C, T+C+St, M+C+St and T+C+P, respectively. In 1999, when irrigation was implemented during planting, the relationship between GLAI and leaf number was more sensitive. The correlation coefficients were very highly significant (P <0.001) with r = 0.962***, 0.947***, 0.948***, 0.958*** and 0.947*** (n = 8), for the treatments T+D, T+C, T+C+St and T+C+P, respectively. The relationship could be explained as the linear equation: Y (GLAI) = B + AX (Leaf numbers). The equation for each treatment is represented on Table 3.4.3.

Table 3.4.3 Regression equations of Green Leaf Area Index (GLAI) with leaf number under different treatment methods at Wang Jia in the 1998 cropping season (non-irrigated treatment)

Treatment		Equation	Rate of R-Sq	F-value	P-value
1998	T+D	y = - 0.861 + 0.325 x	99.6%	1175.62	P <0.001
	T+C	y = - 0.822 + 0.336 x	96.6%	143.50	P <0.001
	T+C+St	y = - 0.710 + 0.303 x	94.6%	87.34	P <0.001
	M+C+St	y = - 0.640 + 0.297 x	97.7%	212.52	P <0.001
	T+C+P	y = - 1.180 + 0.370 x	95.5%	10.29	P <0.001
1999	T+D	y = - 0.085 + 0.177 x	92.5%	62.06	P <0.001
	T+C	y = - 0.269 + 0.211 x	98.9%	53.13	P <0.001
	T+C+St	y = - 0.333 + 0.236 x	90.2%	55.21	P <0.001
	M+C+St	y = - 0.335 + 0.223 x	91.9%	68.37	P <0.001
	T+C+P	y = - 0.424 + 0.291 x	90.3%	55.74	P <0.001

Plant height should also be related to GLAI, if plants develop normally. Typically plants continued to increase in height up to 85-100 days after sowing. Prior to this stage, GLAI had a significant, positive, linear correlation with plant height. After plant growth stopped, GLAI decreased as the maize senesced.

The relationships for 1999 are much weaker than 1998. The linear fit in 1999 is generally very poor, with r = 0.758*, 0.523, 0.522, 0.374 and 0.637 for treatments

T+D, T+C, T+C+St, M+C+St and T+C+P, respectively (n = 8). The relationships in 1998 were relatively strong with r = 0.861**, 0.877**, 0.807**, 0.883** and 0.856** for treatments T+D, T+C, T+C+St, M+C+St and T+C+P, respectively (n = 8). These data showed that the relationship between plant height and GLAI varied markedly with season, but there were few treatment effects.

5) Summary of effects of cultivation techniques on maize GLAI and GLAD

The results show that differences in crop development with different cultivation techniques can vary GLAI and GLAD, but these effects depended on seasonal weather patterns and irrigation. Maize growth was clearly affected by cultivation treatment and the benefits of polythene and straw mulch. These were most evident through visual observation of the crop. Polythene mulch appeared to give higher temperatures and soil moisture if soil had enough moisture before polythene mulch emplacement, which produced rapidly increasing GLAI, leading to a high GLAD during early and middle growth stages. The combination of irrigation and polythene produced the highest GLAI and GLAD. Straw mulch (with both contour planting and minimum tillage) was more beneficial for a higher GLAI and GLAD. When there was no irrigation during planting, straw mulch was effective in maintaining soil moisture to support better growth.

3.5 Measurement of Maize Crop Dry Matter and Yield

Some of the factors affecting crop productivity are long-term, such as soil type and climate type, but management practises can influence crop growth and yield in the short-term. In this section the effects of the cultivation techniques on dry matter production and yield are assessed.

3.5.1 Effects of Cultivation Techniques on Maize Harvest Components

At crop maturity, eight randomly selected plants were sampled by cutting at the stem base, prior to the main plot harvest. These were taken to the laboratory of Yunnan Agricultural University for dry weight and yield component analysis. The total maize yield and biomass of each plot were measured. Samples for each maize plot were selected randomly to determine plot yield. Dry weight analysis of the eight plants sampled on each plot prior to harvest was used to determine the effect of cultivation techniques on above-ground standing biomass (Table 3.5.1 A-C).

Table 3.5.1 Effect of cultivation techniques on maize harvest components analysis of the eight plants sampled prior to harvest at Wang Jia in the 1998 and 1999 cropping season. The data have been analysed by ANOVA with significant differences ($P \leq 0.05$) denoted by different letters

A) 1998 season:

Items	Blocks	Treatments				
		T + D	**T + C**	**T + C + St**	**M + C + St**	**T + C + P**
Dry stem (g/plant)	**Block-A**	22.7	32.5	22.8	29.2	31.0
	Block-B	18.8	22.5	23.0	20.9	34.1
	Block-C	22.9	25.3	18.9	23.6	28.2
Overall mean		**21.5 a**	**26.8 ab**	**21.6 a**	**24.6 a**	**31.1 b**
n = 3, F = 3.798, P = 0.04 <0.05, $LSD_{0.05}$ = 2.9 g						
Dry leaves (g/plant)	**Block-A**	40.9	54.8	45.6	56.8	55.8
	Block-B	35.8	47.1	46.3	38.0	58.1
	Block-C	43.4	48.7	47.1	45.9	55.7
Overall mean		40.0 a	50.2 bc	46.3 ab	46.9 ab	56.5 c
n = 3, F= 4.423, P = 0.026 <0.05, $LSD_{0.05}$ = 4.1 g						
Dry cob	**Block-A**	110.1	153.3	141.5	140.4	158.2
	Block-B	114.4	128.2	126.3	116.9	170.6
	Block-C	114.4	157.1	122.5	132.3	168.5
		113.0 a	**146.2 b**	**130.1 ab**	**129.9 ab**	**165.8 c**
n = 3, F = 11.021, P <0.001 , $LSD_{0.05}$ = 8.5 g						
Biomass g/plant	**Block-A**	173.7	240.6	209.9	226.4	245.0
	Block-B	169.0	197.8	195.6	175.8	262.8
	Block-C	180.7	231.1	188.5	201.8	252.4
Overall mean		**174.5 a**	**223.2 b**	**198.0 ab**	**201.3 ab**	**253.4 c**
n = 3, F = 9.624, P <0.01 , $LSD_{0.05}$ = 13.6 g						
Dry grain (g/plant)	**Block-A**	90.6	127.7	113.1	121.2	128.4
	Block-B	96.5	105.0	104.7	98.3	140.5
	Block-C	94.4	131.6	102.4	102.4	136.8
Overall mean		**93.8 a**	**121.4 bc**	**106.7 ab**	**107.3 ab**	**135.2 c**
n = 3, F = 8.668, P = 0.003<0.05, $LSD_{0.05}$ = 21.6 g						
Harvest index		**0.538 a**	**0.544 a**	**0.539 a**	**0.533 a**	**0.534 a**
Addition items						
Fresh Cob length (cm)	**Block-A**	17.6	17.9	17.1	16.7	18.9
	Block-B	17.5	16.9	18.6	16.8	1.87
	Block-C	18.4	17.8	17.9	17.1	18.2
Overall mean		**17.8 ab**	**17.5 a**	**17.9 ab**	**17.0 a**	**18.6 b**
n = 3, F = 3.801, P = 0.039 <0.05 , $LSD_{0.05}$ = 0.41 g						
Stem girth (cm)	**Block-A**	6.1	6.3	6.4	6.5	7.2
	Block-B	5.8	6.2	6.8	7.1	7.1
	Block-C	6.4	6.5	6.7	6.9	6.9
Overall mean		**6.1 a**	**6.3 ab**	**6.6 b**	**6.8 bc**	**7.1 c**
n = 3, F = 8.152, P = 0.003 <0.01, $LSD_{0.05}$ = 0.20 cm						
No. of rows per cob	**Block-A**	13.8	13.6	13.2	13.2	13.6
	Block-B	13.6	13.2	13.2	13.4	13.2
	Block-C	13.8	12.8	12.8	13.6	13.2
Overall mean		**13.7 a**	**13.2 a**	**13.1 a**	**13.4 a**	**13.3 a**
n = 3, F = 2.958, P = 0.075 >0.05, $LSD_{0.05}$ = 1.0, not significant.						
Grains every two rows	**Block-A**	31.4	30.8	32.4	31.8	36.4
	Block-B	28.6	29.6	33.6	32.1	35.6
	Block-C	32.2	32.2	33.2	32.8	36.2
Overall mean		**30.7 a**	**30.9 a**	**33.1 b**	**32.2 ab**	**36.1 c**

n = 3, F = 11.638 , P <0.001, $LSD_{0.05}$ = 0.9						
Fresh Cob girth (cm)	**Block-A**	16.2	15.8	16.5	17.9	17.8
	Block-B	15.4	15.6	16.7	17.6	18.1
	Block-C	15.1	16.1	16.8	17.5	17.9
Overall mean		**15.6 a**	**15.8 a**	**16.7 b**	**17.7 bc**	**17.9 c**
n = 3, F = 34.297, P <0.001, $LSD_{0.05}$ = 0.25 g						

B) 1999 season (irrigation)

Items	**Blocks**	**Treatments**				
		T + D	**T + C**	**T + C + St**	**M + C + St**	**T + C + P**
Dry stem (g/plant)	**Block-A**	27.46	28.54	27.05	28.49	40.16
	Block-B	19.48	19.49	31.28	20.16	34.70
	Block-C	19.78	23.64	24.25	26.04	34.08
Overall mean		**22.24 a**	**23.89 a**	**27.53 a**	**24.90 a**	**36.31 b**
n = 3, F = 5.59, P = 0.013 <0.05, $LSD_{0.05}$= 3.32 g						
Dry leaves (g/plant)	**Block-A**	50.89	48.99	42.89	51.86	75.90
	Block-B	39.24	38.68	51.46	38.34	61.83
	Block-C	46.78	43.46	43.73	45.48	65.15
Overall mean		**45.63 a**	**43.71 a**	**46.03 a**	**45.23 a**	**67.63 b**
n = 3, F = 8.314, P = 0.003 <0.01, $LSD_{0.05}$ = 4.9						
Dry cob (g/plant)	**Block-A**	152.2	158.6	158.3	152.2	222.2
	Block-B	125.1	126.1	147.3	126.9	189.6
	Block-C	120.7	140.1	131.3	122.5	184.7
		132.7 a	**141.6 a**	**145.6 a**	**133.9 a**	**198.8 b**
n = 3, F = 8.048, P = 0.004 <0.01, $LSD_{0.05}$ = 13.7 g						
Biomass g/plant	**Block-A**	230.6	236.1	228.2	232.6	338.3
	Block-B	183.8	184.3	230.0	185.4	286.1
	Block-C	187.3	207.2	199.3	194.0	283.9
Overall mean		**200.5 a**	**209.2 a**	**219.2 a**	**204.0 a**	**302.8 b**
n = 3, F = 8.528, P = 0.003 <0.01, $LSD_{0.05}$ = 20.6						
Dry grain (g/plant)	**Block-A**	128.21	135.15	134.26	130.11	188.30
	Block-B	104.08	108.19	126.14	107.05	160.88
	Block-C	101.21	117.55	110.20	102.69	155.35
Overall mean		**111.17 a**	**120.30 b**	**123.53 b**	**113.28 a**	**168.18 c**
n = 3, F = 7.568, P = 0.004 <0.01, $LSD_{0.05}$ = 12.0						
Harvest index		**0.554 a**	**0.575 a**	**0.564 a**	**0.555 a**	**0.555 a**
Addition items						
Fresh Cob length (cm)	**Block-A**	17.4	18.6	17.8	18.2	19.4
	Block-B	17.7	16.8	19.0	17.7	18.8
	Block-C	19.9	18.8	18.5	19.9	18.9
Overall mean		**18.4 a**	**18.0 a**	**18.4 a**	**18.6 a**	**19.0 a**
n = 3, F = 0.396, P = 0.807 >0.05, $LSD_{0.05}$ = 0.80, not significant						
Stem girth (cm)	**Block-A**	6.4	6.4	6.6	6.6	7.2
	Block-B	5.8	6.1	7.3	7.4	7.3
	Block-C	6.7	6.7	6.5	7.2	6.7
Overall mean		**6.3 a**	**6.4 a**	**6.8 a**	**7.0 b**	**7.0 b**
n = 3, F = 2.570, P <0.01, $LSD_{0.05}$ = 0.82 cm						
No. of rows per cob	**Block-A**	13.8	12.8	13.3	12.0	13.5
	Block-B	14.1	12.8	13.5	14.0	13.8
	Block-C	14.0	13.3	13.5	13.0	13.8
Overall mean		**13.6 a**	**12.9 a**	**13.4 a**	**13.0 a**	**13.7 a**
n = 3, F = 2.475, P = 0.112 >0.05, $LSD_{0.05}$ = 0.81, not significant.						
Grains every two rows	**Block-A**	28.1	31.8	34.7	32.0	37.0
	Block-B	28.9	29.4	34.1	32.6	37.4
	Block-C	34.7	33.1	32.3	33.8	38.3
Overall mean		**31.5 a**	**31.4 a**	**33.7 a**	**32.8 a**	**37.6 b**
n = 3, F = 5.725, P = 0.012 <0.05, $LSD_{0.05}$ = 3.8						
Fresh Cob	**Block-A**	16.7	16.1	16.4	18.3	17.6

girth (cm)	Block-B	15.9	15.8	17.0	17.5	17.6
	Block-C	15.6	17.2	16.3	17.4	16.3
Overall mean		**16.1 a**	**16.4 a**	**16.6 a**	**17.7 b**	**17.2 b**
n = 3, F = 3.682, P = 0.043 <0.05, $LSD_{0.05}$ = 0.49 cm						

C) 1999 season (non-irrigation)

Items	Blocks	Treatments				
		T + D	T + C	T + C + St	M + C + St	T + C + P
Dry stem (g/plant)	Block-A	24.0	26.5	28.8	30.1	42.7
	Block-B	24.7	23.8	28.5	27.5	37.5
	Block-C	28.7	29.3	29.0	34.3	40.7
Overall mean		**25.8 a**	**26.5 a**	**28.7 b**	**30.6 b**	**40.3 c**
n = 3, F = 15.878, P <0.001, $LSD_{0.05}$ = 2.1 g						
Dry leaves (g/plant)	Block-A	49.1	53.6	55.8	55.8	73.1
	Block-B	38.9	44.7	54.6	55.6	66.4
	Block-C	51.8	53.6	54.1	66.7	74.5
Overall mean		**46.6 a**	**50.6 ab**	**54.9 b**	**59.4 c**	**71.3 d**
n = 3, F = 10.219, P <0.001, $LSD_{0.05}$ = 4.2 g						
Dry cob (g/plant)	Block-A	111.2	132.0	140.9	136.1	168.3
	Block-B	107.7	122.8	134.9	133.9	162.4
	Block-C	130.9	144.3	132.4	169.9	161.5
Overall mean		**116.6 a**	**133.0 ab**	**136.1 ab**	**146.6 c**	**164.1 c**
n = 3, F = 6.469, P = 0.008, $LSD_{0.05}$ = 9.6 g						
Biomass g/plant	Block-A	184.3	212.1	225.5	222	284.1
	Block-B	171.3	191.3	218	217	266.3
	Block-C	211.4	227.2	215.5	270.9	276.7
Overall mean		**189.0 a**	**210.2 ab**	**219.7 ab**	**236.6 b**	**275.7 c**
n = 3, F = 9.155, P = 0.002, $LSD_{0.05}$ = 15.2 g						
Dry grain (g/plant)	Block-A	88.1	106.1	115.9	108.5	137.1
	Block-B	86.4	100.7	109.1	107.9	132.8
	Block-C	106.8	118.7	107.2	139.2	141.6
Overall mean		**93.8 a**	**108.5 b**	**110.7 bc**	**118.5 c**	**137.2 d**
n = 3, F = 6.577, P = 0.007 <0.01, $LSD_{0.05}$ = 8.75 g						
Harvest index		**0.496**	**0.516**	**0.504**	**0.501**	**0.497**
Addition items						
Fresh Cob length (cm)	Block-A	16.9	18.4	17.5	18.4	19.8
	Block-B	17.4	17.5	18.3	16.4	20.1
	Block-C	16.8	17.4	17.1	17.4	19.1
Overall mean		**17.0 a**	**17.8 a**	**17.6 a**	**17.4 a**	**19.7 b**
n = 3, F = 7.728, P = 0.004 <0.01, $LSD_{0.05}$ = 0.52 cm						
Stem girth (cm)	Block-A	5.6	5.6	5.5	6.0	6.7
	Block-B	5.0	5.5	6.1	5.4	6.2
	Block-C	5.3	5.6	5.3	5.3	6.9
Overall mean		**5.3 a**	**5.6 a**	**5.6 a**	**5.6 a**	**6.6 b**
n = 3, F = 6.975, P = 0.006 < 0.01, $LSD_{0.05}$ = 0.30 cm						
No. of rows per cob	Block-A	13.8	12.8	13.8	12.8	14.5
	Block-B	11.8	12.3	13.5	12.3	13.8
	Block-C	12.8	13.3	13.1	12.0	13.5
Overall mean		**12.8 a**	**12.8 a**	**13.5 ab**	**12.3 a**	**13.9 b**
n = 3, F = 4.215, P = 0.041< 0.05, $LSD_{0.05}$ = 0.50						
Grains every two rows	Block-A	31.9	31.5	29.6	32.5	39.3
	Block-B	27.8	29.0	31.2	25.6	37.5
	Block-C	29.4	29.6	27.3	29.1	35.1
Overall mean		**29.7 a**	**30.0 a**	**29.4 a**	**29.1 a**	**37.3 b**
n = 3, F = 6.987, P = 0.006 <0.01, $LSD_{0.05}$ = 1.9						

Fresh Cob	Block-A	16.7	16.7	16.5	16.9	17.2

girth (cm)	**Block-B**	16.2	16.0	17.0	16.5	17.6
	Block-C	16.5	16.5	16.0	15.8	17.0
Overall mean		**16.5 a**	**16.4 a**	**16.5 a**	**16.4 a**	**17.3 b**
n = 3, F = 3.51, P = 0.049, $LSD_{0.05}$ = 0.34 cm.						

From the analyses of maize components of two experimental years, the effects of cultivation techniques were identified. Different cultivation methods exhibited significantly different effects on each investigated item. In 1998, besides the cob row, contour cultivation combined with polythene mulch (T+C+P) had significantly higher stem girth, stem weight, leaf weight, cob girth, cob length, cob weight, grain number every two rows and grain weight than the other four cultivation methods (T+D, T+D, T+C+St and M+C+St). Comparing contour with downslope cultivation, contour cultivation (T+C) showed significantly higher leaf, cob and grain weight than downslope cultivation (T+D). Contour cultivation combined with straw mulch had more beneficial effects on maize components. Treatment T+C+St had significantly higher values of stem girth, cob girth and grain number every two rows than the control (T+D). Minimum cultivation with straw (M+C+St) mulch had significantly higher stem and cob girth than the control (T+D).

In 1999, irrigation was implemented at the time of planting and early growth stages. Contour cultivation plus polythene mulch still showed significantly higher yield components than the other four treatments. Among the other treatments, T+C had significantly higher grain weight than the control. Contour cultivation combined with straw mulch (T+C+St) had two items (cob and grain weight) higher than the control. Minimum tillage plus straw mulch had significantly higher stem and cob girth than the control. The non-irrigation experiment conducted at another site also found similar effects of the different cultivation techniques. There were significant differences in grain weight between treatments.

The results show that different cultivation techniques led to different biomass results, even under the same management. The effects of cultivation methods on maize total biomass were significantly different during the two experimental years. In 1998, contour cultivation combined with polythene mulch exhibited significantly higher biomass than the other four treatments with 45, 13.5, 28.0 and 25.9% than the treatments T+D, T+C, T+C+St and M+C+St, respectively. Meanwhile, contour planting treatment (T+C) also had significantly higher biomass with 27.7% more than downslope cultivation. Although straw mulch did not show significant effects in the 1998 cropping season, both contour and minimum cultivation, combined with straw mulch (T+C+St and M+C+St), showed some benefit for total maize biomass, by 13.5 and 15.4%, respectively, compared with downslope cultivation (T+D).

In 1999, cultivation techniques effects on maize biomass were also significantly different. Contour cultivation plus polythene mulch showed greater effects on biomass than in 1998. T+C+P had significantly higher biomass, at 51.0, 44.7, 38.1 and 48.4% higher than T+D, T+C, T+C+St and M+C+St treatments, respectively. These increases were 5.6, 36.1, 10.0 and 22.6% higher than the increased levels in the 1998 cropping season. There were no significant differences between the other four cultivation techniques. These effects were probably influenced by early irrigation.

The non-irrigation experiment was conducted in a different location. The five cultivation effects were also significantly different from each other. Contour cultivation plus polythene mulch had a higher biomass than the other cultivation methods ($n = 3$, $F = 27.77$, $P < 0.001$, $LSD_{0.05} = 0.58$ tonnes). The increased ranges were very similar to the 1998 results, when no irrigation water was applied. T+C+P had 45.9, 31.2, 25.5 and 16.5% higher biomass than T+D, T+C, T+C+St and M+C+St treatments, respectively. Contour cultivation had 11.2% higher biomass than downslope cultivation. Contour and minimum cultivation had 16.2 and 26.2% higher biomass than downslope cultivation, respectively. These results on the same non-irrigated treatments, in the same year of 1999, proved the importance of early irrigation during maize growth in upland Yunnan.

3.5.2 Effects of Cultivation Techniques on Maize Air-dry Yield

Besides the sampled crop, total plot yield was measured by weighing the fresh cob in the field and samples were measured air-dry (35^{o}C for 48 hours) in the laboratory at Yunnan Agricultural University. The total air-dried yield for each plot, compared with the sampled plant (converted to tonnes per hectare), are presented in Table 3.5.2.

Table 3.5.2 The comparison of sampled yield with air-dry grain yield of maize from each block at Wang Jia Experimental Site during the two experimental years in 1998 and 1999, converted to tonnes per hectare and analysed by ANOVA with significant differences (P ≤0.05) denoted by different letters

Year	**Yield determination**	**Blocks**	**Treatments**				
			T + D	**T + C**	**T + C + St**	**M + C + St**	**T + C + P**
1998	Yield from sampled plant	**Block-A**	5.5	7.7	6.9	7.4	7.8
		Block-B	5.9	6.4	6.4	6.0	8.5
		Block-C	5.7	8.0	6.2	6.2	8.3
		Mean	**5.7 a**	**7.4 b**	**6.5 ab**	**6.5 ab**	**8.2 c**
		n = 3, F = 8.535, $P < 0.003$, $LSD_{0.05}$ = 1.0 t					
	Yield from each plot	**Block-A**	4.4	5.6	4.7	5.2	5.8
		Block-B	4.0	5.2	5.0	4.6	5.4
		Block-C	4.6	5.4	5.2	5.0	5.8
		Mean	**4.3 a**	**5.4 bc**	**5.0 b**	**4.9 b**	**5.7 c**
		n = 3, F = 11.320, P = 0.001, $LSD_{0.05}$ = 0.41 t					
1999 irrigation	Yield from sampled plant	**Block-A**	7.8	8.2	8.1	7.9	11.4
		Block-B	6.3	6.6	7.7	6.5	9.8
		Block-C	6.1	7.1	6.7	6.2	9.4
		Mean	**6.7 a**	**7.3 a**	**7.5 b**	**6.9 a**	**10.2 c**
		n = 3, F = 7.578, P = 0.004, $LSD_{0.05}$ = 0.6 g					
	Yield from each plot	**Block-A**	6.4	7.6	7.5	6.2	9.2
		Block-B	5.8	6.7	7.2	6.0	9.5
		Block-C	5.7	7.2	7.3	6.1	8.6
		Mean	**6.0 a**	**7.2 b**	**7.3 b**	**6.10 a**	**9.1 c**
		n = 3, F = 40.282, P = 0.001, $LSD_{0.05}$ = 0.5 t					
1999 non-irrigation	Yield from sampled plant	**Block-A**	5.3	6.4	7.0	6.6	8.3
		Block-B	5.2	6.1	6.6	6.5	8.1
		Block-C	6.5	7.2	6.5	8.4	8.6
		Mean	**5.7 a**	**6.6 ab**	**6.7 ab**	**7.2 c**	**8.3 c**
		n = 3, F = 6.706, P = 0.007, $LSD_{0.05}$ = 1.0 g					
	Yield from each plot	**Block-A**	5.0	5.8	6.1	6.1	7.6
		Block-B	5.1	5.6	6.4	6.2	7.5
		Block-C	5.7	5.9	6.1	6.9	7.8
		Mean	**5.3 a**	**5.8 ab**	**6.2 bc**	**6.4 c**	**7.6 d**
		n = 3, F = 28.711, $P < 0.001$, $LSD_{0.05}$ = 0.22 t.					

Generally, air-dry yield contained 10-20% moisture. However, it is more comparable to the local government statistics data, which are usually the air-dry data. Furthermore, the plot yields are more comparable to the large scale production, as it minimises errors from the subjectivity of people when sampling.

Comparing the grain yield from the sampled plants and total yield from each plot, there were some differences from each other on the final yield. Sample plant yield had higher yield than the total plot yield. This was probably caused by the edge effect for each plot was separated from each other and different crops were planted around the plots. However, the differences among the different cultivation techniques from both sampled plant and total plot yield were similar. It indicated the differences between the cultivation techniques observed from the sampled plant can be representative of differences between treatments.

Comparing the effects of cultivation techniques on the crop yield from two years, contour planting cultivation combined with polythene mulch produced the highest yield in all blocks and showed significant differences with other treatments during two experimental years. In 1998, T+C+P exhibited higher grain yields, with means of 43.9, 11.3, 26.2 and 25.5% higher than T+D, T+C, T+C+St and M+C+St treatments, respectively. Both contour and minimum cultivation plus straw mulch (T+C+St and M+C+St) had significantly higher yield, with 14.0 and 14.6% more than the control (T+D). Contour cultivation significantly increased maize yield by 29.2% more than downslope cultivation. When compared with the plot yield, T+C+P had 32.5, 4.9, 14.1 and 14.9% higher yield than T+D, T+C, T+C+St and M+C+St treatments, respectively. Both contour and minimum cultivation plus straw mulch (T+C+St and M+C+St) had significantly higher yield, with 14.0 and 13.8% more than the control (T+D). Contour cultivation significantly increased maize yield, with 24.6% higher than downslope cultivation.

In 1999, the maize yield was notably increased because of irrigation at the time of planting and early growth stages. Effects of cultivation techniques were still very significant between treatments. Contour cultivation combined with polythene had a significantly higher yield on a plant basis by 52.2, 39.7, 36.0 and 48.5% compared with T+D, T+C, T+C+St and M+C+St treatments, respectively. Treatments T+C and T+C+St had 8.4 and 11.4% higher yield than T+D, respectively. Minimum tillage did not show any significant increase in yield, but was still ~2.0% higher than T+D treatment. When compared with the differences from the plot yield, the increased ranges were similar. T+C+P had 51.6, 27.0, 24.1 and 49.2% higher yield than T+D, T+C, T+C+St and M+C+St treatments, respectively. T+C and T+C+St had 20.1 and 22.9% higher yield than T+D, respectively. Contour cultivation significantly increased maize yield by 2.2% more than downslope cultivation.

On the experiment carried out at another site and without irrigation, the effects of cultivation techniques on maize yield were similar to the 1998 results. From the sampled plants, T+C+P had a higher mean grain yield; 47.1, 26.9, 24.4 and 16.3% higher than T+D, T+C, T+C+St and M+C+St treatments, respectively. T+C+St and M+C+St had significantly higher yields with 15.9 and 18.2% more than the control (T+D). Contour cultivation significantly increased maize yield by 26.5% more than downslope cultivation. When compared with the plot yield, T+C+P had 44.9, 32.4, 23.1 and 19.3% more than T+D, T+C, T+C+St and M+C+St treatments, respectively. T+C+St and M+C+St had significantly higher yield, with 9.5 and 17.7% more than the control (T+D). Contour cultivation significantly increased maize yield by 21.5% more than downslope cultivation.

3.6 Effects of Cultivation Treatment Techniques on Winter Crop Yield

Wheat (cv. *Yunmai No. 4*) was planted in 1998 under non-irrigation and 1999 under irrigated conditions, respectively, following the maize harvest. The results of two years are given in Table 3.6.1.

Table 3.6.1 Wheat air-dry yield in 1998 (non-irrigated) and 1999 (irrigation) at Wang Jia Experimental Site, analysed by ANOVA with significant differences (P ≤0.05) denoted by different letters

Year	Previous Treatment	Block I	Block II	Block III	Mean (t ha^{-1})
1998	**T+D**	2.45	0.94	1.61	**1.67 a**
	T+C	2.13	1.57	1.48	**1.73 a**
	T+C+St	2.13	1.92	1.18	**1.75 a**
	M+C+St	1.50	1.80	1.96	**1.75 a**
	T+C+P	1.75	2.11	1.57	**1.81 a**
1999	**T+D**	2.75	2.84	2.78	**2.79 a**
	T+C	2.65	2.62	2.36	**2.54 a**
	T+C+St	2.68	2.83	2.21	**2.57 a**
	M+C+St	3.14	2.71	2.89	**2.91 a**
	T+C+P	3.12	3.25	2.65	**3.01 a**

The results showed that some yield could be gained, even it was very dry during the winter season at Wang Jia. It was a valuable attempt in the hilly land, where people lack crops. Especially, after the irrigation system was established, winter wheat yield increased under irrigation. Compared with the wheat yield in 1998, non-irrigation with 1999, under irrigation, the yield increased 47-67%.

3.7 Analyses of the Relationship between Maize Components and Other Factors under Different Cultivation techniques

Final maize yield (biomass and grain) was a composite result of all internal and external factors. In this section the relationship between yield and other measured parameters are explored.

3.7.1 The relationship between crop yield and soil parameters under different cultivation methods

There are many soil parameters that affect final maize production. Here just three of them, soil moisture, temperature and major nutrients are discussed.

The correlation of soil temperature are divided into two stages for the purposes of this discussion (according to the analysis of soil temperature in Chapter 3.3, soil temperature showed effects on maize growth before 70 days after sowing). Firstly, the early growth stage, when temperature behaved differently between treatments. Secondly, after 70 days the stage when there were less significant differences in temperature between the treatments. The results are shown in Table 3.7.1.

Table 3.7.1 The correlation coefficient of soil temperature and maize yield during two different growth stages before and after 70 day from sowing at Wang Jia in 1999 (n = 5)

Soil depth (cm)	Before 70 days	After 70 days	Whole stage
0	0.974***	0.938*	0.970**
5	0.972***	0.955*	0.964**
10	0.965**	0.860*	0.946*
15	0.962**	0.896*	0.943*
20	0.937*	0.887*	0.926*

"*" --- Correlation is significant at P <0.05;
"**" --- Correlation is highly significant at P <0.01;
"***" --- Correlation is highly significant at P <0.001.

These correlation results indicate that soil temperature was one of the important factors during the whole maize growth stage, but especially at the early stage. Concerning soil depth, 0-15 cm depth was particularly important for maize, with many fine roots present at this depth. Establishing a higher soil temperature condition at an early stage was an important basis for increased grain growth during later growth. Polythene mulch met this requirement, as discussed in the temperature section.

Soil moisture had significant correlations with yield. Due to the rainfall pattern in Yunnan, which is located in the monsoon climatic zone, there is a very clear summer rainfall season. Rainfall usually varies considerably, especially in early spring. According to the statistics of the long term weather data analysis, spring drought is a major problem in Yunnan Province (Yunnan Meteorological Statistics, 1996). Table 3.7.2 shows the correlation coefficients between soil moisture and crop yield.

Table 3.7.2 The correlation of soil moisture and maize yield during two different growth stages before and after 55 days from sowing at Wang Jia in 1999 (n = 5)

Soil depth (cm)	Before 55 days	After 55 days	Whole stage
0-5	0.874*	-0.821*	-0.411
5-10	0.918**	-0.657	-0.169
10-15	0.981***	-0.378	0.016

"*" --- Correlation is significant at P <0.05;
"**" --- Correlation is highly significant at P <0.01;
"***" --- Correlation is highly significant at P <0.001.

The correlation coefficients indicate that soil moisture at the early growth stage was very important for grain yield. Soil moisture at different depths had a significant correlation with grain yield before 55 days after sowing. From May to early July was the important period of water requirement for maize growth. In the main rainy season, however, soil moisture did not show much relevance to yield. This means that from July onwards, water was not the main limiting factor for maize growth. At the same time, excess water inhibited growth, because it caused low soil temperatures and influenced root development.

Besides the relationship with soil properties, crop yield was influenced by planting direction, tillage methods, and mulching materials by using mean values of 8 samples from 3 replications (Table 3.7.3).

Table 3.7.3 The correlation of planting direction, tillage methods and mulching material with maize yield under two irrigation treatments at Wang Jia in 1999 (n = 8). The data calculated using mean values of 8 sampled plants located at different points in the 3 replicate plots

Relation item to Yield	Irrigation	Non-irrigation	Compared treatment
Planting direction	0.922**	0.964***	T+D vs. T+C
Tillage	0.847**	0.715*	T+C+St vs. M+C+St
Straw mulch	0.491	0.746*	T+C vs. T+C+St
Polythene mulch	0.942***	0.924**	T+C vs. T+C+P

"*" --- Correlation is significant at P <0.05;
"**" --- Correlation is highly significant at P <0.01;
"***" --- Correlation is highly significant at P <0.001.

On the sloping fields, planting direction influenced yields significantly both under irrigated and non-irrigated systems when the field was cultivated in the traditional way. Contour planting gave higher yields than downslope planting when other treatments were the same.

These analyses indicated that cultivation under irrigation increased crop yield. When irrigation was available, tilling the field produced higher productivity. If water was unavailable, there was evidence for relationships and tillage was important. The main reason may be that local soils are quite heavy and very compact. In this condition, cultivation can improve aeration and assist root penetration.

Polythene mulch markedly increased crop yield, both under irrigated and non-irrigated systems. Under irrigation, polythene gave a strong significant correlation with final grain yield. At the same time, the relationship of polythene and yield was not so strong under the non-irrigated condition. As discussed earlier, polythene mulch could maintain higher soil moisture if there was sufficient soil moisture before placing the mulch. If there was insufficient soil moisture before putting on polythene, the polythene prevented evaporation, with a limited effect on maintaining soil moisture. It is very important to ensure sufficient soil moisture is present before application of the polythene, in order to bring into play the full effectiveness of the mulch.

3.7.2 Relationship between crop yields and crop development under different cultivation techniques

Besides the above external factors influencing crop yield, there are important internal factors, such as GLAD, height growth rate and stem girth. The relationship of these factors with final grain yield under two irrigation conditions are shown in Table 3.7.4.

Table 3.7.4 Correlation of plant parameters with crop yield under two irrigation systems at Wang Jia in 1998 and 1999 (n = 5)

Item and year	1998	1999	
Correlation parameters	Non-irrigation	Irrigation	Non-irrigation
GLAD (days)	0.884*	0.964**	0.971**
Height growth rate (cm/d)	0.944**	0.976***	0.962**
Stem girth (cm)	0.864*	0.887***	0.967**

"*" --- Correlation is significant at P <0.05;
"**" --- Correlation is highly significant at P <0.01;
"***" --- Correlation is highly significant at P <0.001.
Height growth rate = plant height/growth days.

The correlation coefficient of GLAI with grain yield was calculated from the mean value of GLAI during the growing season. The mean value of the whole season was reasonably representative of the effects of the different cultivation techniques. Correlation was considered using data from all treatments. This analysis shows that GLAD was correlated with final grain yield. Both irrigated and non-irrigated treatments in 1998 and 1999 more significantly correlated with the final grain yield. High GLAD means rapid and successful crop growth, which determines the assimilation potential of the crop, thereby linking to yield.

Increase in plant height stopped ~85 days after sowing. Therefore, the early growth stage was a key period for plant height. The development of a high canopy may be important to final yield. The height growth rate was calculated up to 85 days after sowing. It had a very significant correlation with grain yield, both on irrigated and non-irrigated systems.

Stem girth was measured after harvesting the 8 sampled plants. Girth is an indication of dry matter production in maize and may reflect growing conditions. Good growth conditions led to higher stem diameters. The correlation of girth with yield under non-irrigation was higher than under irrigation, but both were significant. Since stem girth is a function of dry matter production, this is likely to be related to yield. There is no evidence to establish cause and effect, this possible relationship is only suggested.

3.7.3 Crop Yield Relative to the Main Nutrition Elements

According to the soil analyses during the period 1997 to 1999, soil nutrients in the experimental site were variable, especially available nutrients. During the experiment, standardisation of fertilisers highlighted the importance of nutrients. After two years of treatment, the relationship between fertiliser and yield appeared. After analysing the correlation coefficients of available N, P and K with the 1999 yield, the correlation coefficients were only $r = 0.613^*$, 0.503 and 0.175 ($n = 15$), respectively. These soil samples collected from the zigg points, but not the exactly maize root location, which caused some differences from the analysed results with the nutrients absorbed by the maize. However, there were still many positive relations between yields and nutrients, but these correlations were not significant. The change of soil nutrients is a long-term process and it needs many years of investigation to clarify the effects.

3.8 Cost Benefit Analysis

To be a useful any new technique, must have economic benefits and be implemented and accepted by most farmers. Furthermore, it must be easy to obtain any required new materials and these must not damage the environment. These are issues which influence the sustainability of a technique. Here the benefits of different cultivation methods and problems during their implementation are discussed. Table 3.8.1 shows the inputs and outputs of different cultivation methods and Table 3.8.2 shows the economic assessment of irrigation systems established on the sloping fields.

Table 3.8.1 Cost benefit analysis of different treatment methods at Wang Jia Experimental Site in 1999

Treatment	Inputs					Outputs			Difference * (Yuan ha^{-1})
	Cultivation (Yuan ha^{-1})	Mulch material (Yuan ha^{-1})	Fertiliser (Yuan ha^{-1})	Inter tillage (Yuan ha^{-1})	Total input (Yuan ha^{-1})	Yield (T ha^{-1})	Gross value (Yuan ha^{-1})	Net income (Yuan ha^{-1})	
T+D (CK*)	150	0	100	20	270	6.7	1005	735	-
T+C	150	0	100	20	270	7.3	1095	825	90
T+C+St	150	45	100	20	315	7.5	1125	810	75
M+C+St	0	45	100	20	315	6.9	1035	870	135
T+C+P	200	120	100	20	390	10.8	1620	1230	445

Table 3.8.2 Assessment of the economic benefit of irrigation over the long-term on hilly land in Yunnan

Treatment	Inputs					Outputs				
	Total input (Yuan)	Depreciation (Years)	Yuan/yr	Irri area (ha)	Total (Y ha^{-1})	Irrigation (t ha^{-1})	Non-irrigation (t ha^{-1})	Increase (t ha^{-1})	Increase (Yuan ha^{-1})	Net increase in income (yuan ha^{-1})
T+D (CK)	80000	20	4000	10	400	6.7	5.8	0.91	1365	965
T+C	80000	20	4000	10	400	7.3	6.6	0.72	1080	680
T+C+St	80000	20	4000	10	400	7.5	6.7	0.83	1245	845
M+C+St	80000	20	4000	10	400	6.9	6.6	0.30	450	50
T+C+P	80000	20	4000	10	400	10.8	8.1	2.64	3960	3560

* CK is the control treatment; here all benefits were compared with downslope planting.

* Exchange rate: £1 = ¥13.5.

This cost benefit analysis shows that just changing planting direction without any other treatment could increase net income by 90 Yuan ha^{-1} (£6 ha^{-1}). Contour planting is therefore a useful method on sloping land, when no other technique can be employed. With straw mulch treatment, the net income could increase to 75 and 135 Yuan (£6 and £10) for treatments T+C+St and M+C+St, respectively. Polythene mulch gave the highest net income compared with the other treatments, with 445 Yuan ha^{-1} (£34) increase in income over the control (T+D) and had 365, 380 and 325 Yuan ha^{-1} (£27, 28 and 24) greater income than T+C, T+C+St and M+C+St treatments, respectively. Polythene mulch methods appear to be the most economic method to increase yields profit on sloping land. The main issue relating to its use is problem of disposal and possibly the use of non-renewable resources for production. This could limit use in the long-term.

Considering the irrigation system, this is a long-term engineering facility. The benefits of this system must be considered over 20 years. The early investment in the irrigation system could not be afforded by a single farm. It must be invested by local government. According to the depreciation calculation, the irrigation facility can last at least 20 years. Although the data came from two years, 1998 under non-irrigation, 1999 under irrigation, from this simple analysis, it appears to be a valuable investment. The system could increase yield 0.91, 0.72, 0.83, 0.30 and 2.64 tonnes ha^{-1} for treatments T+D, T+C, T+C+St, M+C+St and T+C+P, respectively. Calculating for the market price for maize in 1999, 1.50 Yuan kg^{-1} (£0.12/kg), converting to the economic value, the increased values are 965, 680, 845, 50 and 3560 Yuan ha^{-1} (£74, 52, 65, 4 and 274 ha^{-1}), respectively. Wang Hongzhong *et al*. (1999) assessed the return rate of the economy in Xiangyun County, Yunnan Province. His results showed that the local government invested the funding, while the farmer input the labour. An expenditure of 500 Yuan (£40) could establish a 150 m^3 water pond, which could irrigate 1 hectare of upland over ~20 years. The net increase in yield was ~1.5 t ha^{-1} per year. The investment could be returned during 4-5 years. Therefore, from a long-term view, irrigation is a very valuable investment on hilly land when there is a water resource to supply water ponds. This analysis does not consider alternative uses for the water, as the annual supply is not limiting.

3.9 Summary of Results

The following summary points can be made with regard to the results:

1) Monthly rainfall and total rainfall distribution at Wang Jia varied considerably during the two growing seasons, but the annual rainfall was very similar. In 1998, the total rainfall was 1032 mm compared to 1025 mm in 1999, mainly concentrated from May to September, with ~85.5% of the total. The mean rainfall of the two experimental years was 1028.5 mm, close to the long-term mean of 1020 mm at Kedu Township (Yunnan Meteorological Station, 1995). The monthly rainfall of June 1999 was very low with 81.1 mm, just 38.7% of that of 1998. Less rainfall in June affected maize growth.

2) Soil temperature was affected by the cultivation techniques to different degrees in each season, but generally polythene mulch had greater effects on soil temperature during the early crop growth stage than straw mulch. As the canopy enlarged, the effects became less. Forty days after sowing, there were no significant differences between mulch and non-mulch treatments. Straw mulch caused lower soil temperatures during the day time, but maintained higher temperatures at night. Soil temperature varied over a larger range when the soil was dry.

3) Considering the overall seasonal trends for each treatment, the effects of polythene and straw mulches in increasing soil moisture were clear. Polythene mulch maintained soil moisture when the soil contained considerable moisture before the polythene was applied. But if the soil was dry, subsequent rainfall was separated from soil by the polythene, which caused soil moisture to be lower until the water infiltrated from unmulched areas. In this situation, irrigation was necessary. Straw mulch was not as effective as polythene at the early growth stage, but it still maintained a significantly higher soil moisture during the whole growing season than the control treatment. In particular, when there was insufficient rainfall or irrigation before or after planting, straw mulch appeared to maintain higher soil moisture than the other treatments.

4) Soil bulk density was affected by a several factors, but the differences were relatively small. Firstly, traditional cultivation tended to increase soil bulk density over two years. Secondly, straw mulch was beneficial to soil bulk density, as the decayed material helped soil form a good structure, leading to a lower soil bulk density. Thirdly, polythene mulch protected the surface soil from the impact of raindrops, which caused lower soil bulk density during the early and middle growth stages, but did not have any beneficial effects on soil structure.

5) Soil penetrometer readings were interrelated to soil moisture and structure. When soil structure improved or soil moisture increased, penetrometer readings decreased. Polythene mulch prevented raindrop splash compaction, which led to lower penetrometer readings during the whole growth stage. Generally, there were few significant changes in resistance over the two years of experiments.

6) Changes in soil chemical properties over the period 1997 to 1999 were very difficult to identify. Generally, total forms of N, P and K showed more consistent trends than available forms. Total N increased on almost all plots, while total P showed the reverse effect with time. Soil nutrients were affected by planting direction and mulching methods have as shown by changes in the main nutrient factors (soil organic matter, total NPK, available NPK and pH) and other nutrients (CaO, Fe_2O_3, K_2O, MgO, P_2O_5, Cu, S). Mulch, including straw and polythene mulch, was an efficient method to prevent nutrients being washed away by runoff and maintained an even nutrition level along the slope during the rainy season. The decayed straw is beneficial to increasing soil organic matter and total and available nitrates, which improved soil structure and increased soil pH. Contour planting maintained nutrients more than downslope planting.

7) Change in median soil particle size were small over the two years, but there were some minor treatment effects. Contour planting (T+C and T+C+P) decreased median values, while straw mulch treatment increased values. Contour planting had positive effects on soil median particle size, as contour planting retained more fine soil on the plots. Straw mulch helped soil form a relatively larger particle size, which caused median values to significantly increase over three years and

confirms the notion that the soil did not become relatively finer with time. Minimum tillage exhibited an increase in relative sand content. Generally, contour planting significantly increased clay content during the three year period.

8) The effects of cultivation techniques on plant height, Green Leaf Area Index (GLAI), Green Leaf Area Duration (GLAD), standing biomass, yield and yield components were very significant during the two years of experiments.

9) According to the input and output analysis, compared with the control treatment, the four treatments had different beneficial levels. Contour cultivation combined with polythene mulch increased income by 445 Yuan ha^{-1} compared with the control. T+C, T+C+St and M+C+St increased by 90, 75 and 135 Yuan ha^{-1} compared with the control, respectively.

10) Irrigation had a marked effect on with all crop growth parameters and the final yield. Irrigation was one of the most important routes to improve the productivity on the hilly land in Yunnan. Assessments indicated that irrigation systems had high economic value in the long-term.

Chapter 4: General Discussion and Conclusions

Introduction

The primary aim of this investigation has been to investigate the effects of cultivation techniques (developed partly because of their potential to improve soil conservation) on the soil characteristics and productivity of maize on sloping land in the highlands of Yunnan Province. A two-year programme of field experimentation, linked to detailed plant and soil analysis, has been carried out in Wang Jia Catchment using plots maintained by local farmers. This chapter discusses the results from the field plot studies in relation to other published work and attempts to draw some general conclusions on the effectiveness of the evaluated techniques. It then identifies some areas for improvement with some suggestions for further research.

4.1 Effects of Cultivation Techniques on Soil Characteristics

4.1.1 Effects of cultivation techniques on soil temperature

As a tropical and sub-tropical crop, high temperatures (including air and soil temperature) are very beneficial for maize growth and yield. Walker (1969) reported that dry weight and total leaf length of developing maize seedlings reached a maximum at soil temperatures of between 26-27^{0}C. Allmaras *et al.* (1964) quoted an optimal soil temperature for maize growth of 27.4^{0}C, based on their work in the northern USA. However, high temperatures can also reduce yields. Harrison *et al.* (1979) at the International Institute of Tropical Agriculture (IITA) in Nigeria, noted that yield could be reduced by supra-optimal temperatures, as observed in one experiment. They documented that in their particular climate (>40^{0}C), when maximum soil temperature was increased by only 2^{0}C, maize yield could be reduced by ≤30%. At Wang Jia, mean air temperature and soil temperatures were 24.9^{0}C and 19.4^{0}C, respectively, during the maize-growing season from May-October. Considering the optimal maize growth temperature, air temperature was 2^{0}C lower during all growth stages. According to the field measurements, the mean daily air temperature during the vigorous growth stage, May-August, was 25.5^{0}C, which was still a little lower than the optimum temperature. Therefore, at Wang Jia, adopting some suitable methods to increase soil temperature will be beneficial for maize growth.

The use of clear polythene mulch is well known to for increasing soil temperature, even though some adverse effects of clear polythene mulch are also evident (Harrison *et al.*, 1979). During two experimental years at Wang Jia, contour cultivation with polythene mulch markedly increased soil temperature during the early growth stages (≤45 days after sowing). The mean temperature at 0-20 cm soil depth was 26.8^0C during the day, which was 2.9, 3.7, 4.0 and 3.6^0C higher than T+D, T+C, T+C+St and M+T+St treatments, respectively. These indicated that under T+C+P treatment, the temperature was closer to the optimum growing requirement of maize compared with other cultivation techniques. If soil temperatures were >40^0C, negative effects of the mulch would probably be observed (Harrison *et al.*, 1979). Since soil temperatures measured on the plots in this study never exceeded these values, and given that soil temperatures under the polythene were higher than other treatments, the effects should have been beneficial.

Other treatments, such as contour and minimum cultivation combined with straw mulch, showed temperature differences from the control (T+D). Generally, the mean soil temperature at 0-20 cm depths was $0.5\text{-}1.2^0$C lower than unmulched treatments. This lower temperature effect, on the other hand, reduced evaporation during the dry season. Liu Zhenyu *et al.* (2000) found the same effects by using different mulching methods in dryland maize in Shanxi, China. Their results showed that the temperature of straw mulch was $0.5\text{-}2^0$C lower than the control. The lower temperature decreased evaporation, increasing water use efficiency and improved root growth, which led to higher grain yield. Meanwhile, straw mulch maintained a higher soil temperature than on bare fields at night. The results at Wang Jia showed that the temperature of straw mulch treatments was $0.5\text{-}1.5^0$C higher than the control in the morning (0730-0830). Aina (1981) found similar effects of straw mulch on sandy loam soils in Nigeria.

4.1.2 Effects of cultivation techniques on soil moisture

As discussed in Chapter 3, the monsoon climatic regimes have four clear seasons. Spring drought is a common phenomenon in Yunnan. The limiting factor for spring crop planting is usually soil moisture. A number of methods have been used by farmers, such as mulching and irrigation, to alleviate spring drought and increase yields in the highlands of Yunnan. Polythene mulch has been widely adopted for cash crops in these areas (e.g. tobacco), but the use of straw mulch is rare.

The main effect of straw mulch was probably on the maintenance of soil moisture (Moody *et al.*, 1963). Considering the effect of the different cultivations combined with different mulch materials on soil moisture, there appeared to be a positive effect throughout the season using either polythene or straw mulch. Seasonal means for 1998 and 1999 were different on the polythene mulch, as there was irrigation in 1999, but no irrigation in 1998 at the early growth stage. The effect of polythene mulch depends on timeliness of application. In 1998, there was no irrigation during planting and soil moisture was lower under polythene mulch. Furthermore, the impermeability of the polythene prevented moisture penetrating into the surface soil, causing lower soil moisture under polythene mulch. Soil moisture was a mean 4.0% (27.0 and 23.0% under straw and polythene mulch, respectively, at 45 day after sowing) lower than straw mulch (T+C+St). This indicates that the effects of the straw mulch on moisture under different cultivation methods are very marked during the early dry season. Such effects were also found by Liu Zhenyu *et al.* (2000) in the dry lands of Shanxi, where straw mulch treatments had 0.7-5.0% higher soil moisture levels than unmulched treatments. The high temperature effects under polythene did not produce effects on the crop until there was sufficient soil moisture. Conversely, straw mulch could maintain the limited soil moisture, which easily infiltrated after rainfall, resulting in higher soil moisture than polythene mulch when there was no irrigation.

Barton (1999) found similar effects in Yunnan, that the beneficial effects of straw mulch were evident when periods of moisture stress occurred at critical times of crop growth. Simpson and Gumbs (1986) also found beneficial effects of applying straw mulch over conventional tillage without mulch, in their study on a heavy clay soil in Guyana. They found mulched plots had a higher soil moisture content at both 0-15 and 15-30 cm depths compared to unmulched plots, which was particularly beneficial during drought stress periods, when soil moisture was kept within the available range for plant growth (between permanent wilting point and field capacity) for most of the season. The study of Rathore *et al.* (1998) on a deep clay soil of Madhya Pradesh, India, showed that straw mulch conserved more water in the soil profile during the early growth period, compared to no mulch. Subsequent release of conserved soil water regulated plant water status, soil temperature and lowered soil mechanical resistance. This led to better root growth and higher grain yield of both chickpea and mustard in the straw-mulched plots than in the non-mulched plots.

When there was sufficient soil moisture, such as with irrigation before polythene emplacement, the effects of polythene on maintaining moisture became very clear. Contour cultivation combined with polythene treatment (T+C+P) had 2-3% (26.7%), higher moisture than other treatments (mean 24.5, 24.6, 24.3 and 23.6% for M+C+St, T+C+St, T+C and T+D, respectively). The effects of polythene depended on the amount and distribution of rainfall since, under conditions of high rainfall over long periods, soil saturation can be increased. Simpson and Gumbs (1986) also found this, due to the heavy nature of their soils and reduced evaporation beneath the mulch, which can hinder plant development.

It is likely that both soil moisture and soil temperature must be given due consideration when comparing different cultivation techniques. From the data available, it is not possible to ascertain which of these two effects is more important. Consideration of the rainfall regime would also be required, since in 1998 the relationship between soil moisture, soil temperature and maize development was more ambiguous, because of the low soil moisture before polythene emplacement. The relationships in 1999 were clearer. Combining rainfall, temperature and relative humidity, the effects of weather on maize growth at Wang Jia can be assessed. Application of sufficient water to maize during the early growth season was probably the main management strategy for increasing crop productivity at Wang Jia and similar areas in Yunnan Province. Future work must investigate these related changes more closely, by continuous monitoring with *in-situ* sensors linked to data-loggers (Section 4.5).

4.1.3 Effects of cultivation techniques on soil bulk density

Bulk density is an essential accompaniment to soil C, N and P measurements. With soil C, it can be used to derive porosity. Changing soil bulk density is a long-term process, which relates to soil cultivation, organic fertiliser use and planting crops. Different soil textures have their own optimum density. According to the statements of optimum density of Jones (1983), who studied the soil texture on critical bulk densities for root growth, the optimum bulk density of soils of similar texture to those at Wang Jia, was ~1.25 g cm^{-3}. A 20% drop in root proliferation would be expected if the bulk density rose to ~1.5 g cm^{-3} (Barton, 1999). A high soil bulk density is evidence of soil compaction, which is not beneficial to root development. Conversely, the low soil bulk density can cause available nutrients to be quickly lost (Zhu Zhuanlin, 1999).

Based on two years of measurements, some general soil bulk density changes under different cultivation techniques were evident. The results showed the effects of different cultivation on soil bulk density occurred mainly in the 0-10 cm soil depth from the beginning of 1998 to the end of 1999. The data indicate that straw mulch was beneficial for soil bulk density. After using straw mulch, the density tended to decrease, from 1.31 and 1.33 g cm^{-3} at the beginning of 1998 to 1.25 and 1.31 g cm^{-3} at the end of 1999 for treatments T+C+St and M+C+St, respectively. Straw mulch improved soil structure in two ways. Firstly, the decayed straw was conducive to the development of stable soil fragments. Secondly, decayed straw increased SOM contents, which were beneficial for soil structure. Wang Li (1994) also found this trend and found that the decay of straw was one of the main resources for minimum tillage fields in the uplands of Shanxi Province, China.

Other treatments, from a long-term view, had little effect on soil bulk density. Polythene mulch did not essentially affect soil structure. Cultivation plus polythene mulch could prevent raindrop impact and maintain a lower soil bulk density, but still had an increased density over the two years from 1.21 (1998) to 1.26 (1999) g cm^{-3}. For the other two treatments (T+D and T+C), the soil bulk density increased from 1.27 and 1.26 kg cm^{-3} to 1.28 and 1.29 kg cm^{-3}, respectively. Cultivation decreased the soil bulk density at the beginning, but did not have any long-term benefit for the improvement of soil bulk density.

The bulk density measurements indicated that as well as differences occurring between the two depths studied, there were also some differences between the start and end of the cropping season in 1999. Generally, for the same treatment, soil bulk density increased during the growing season. The bare soil surface treatments T+D and T+C increased more than mulched treatments, because the mulch prevented rainfall compaction, especially on the polythene mulch. Minimum tillage treatment exhibited a permanently higher soil bulk density than tillage treatments, because of the lack of disruption to the surface soil. Similar results on the effects of treatments on bulk density were observed by Hulugalle *et al.* (1990), based on fieldwork at Onne, Nigeria. Bulk density at 0-10 cm depth under no-tillage was greater than under a mulched plot. The authors also noted that bulk density increased at both depths over the trial period, from 1983-1988. Conversely, Simpson and Gumbs (1986) found that mulching had no significant effect on soil structural parameters, including bulk density and porosity at 0-5 cm depth, on a heavy clay soil in Guyana. However, there were no significant differences between values at the start and end of the season on the same treatments, attributed to cultivation during the winter season.

Besides minimum tillage treatment at the start of the season, the highest bulk density values were generally at 10-20 cm depth, with lower values at the 0-10 cm depth for other cultivation techniques. This would have resulted from recent tillage operations, breaking up large soil clods and loosening the soil. However, at the end of the season, the reverse effect occurred, with almost all treatments exhibiting a higher bulk density in at 0-10 cm than at 10-20 cm depth. It is also worth noting that with most treatments, bulk density increased through the season, especially on no-mulch treatments. This increase was mainly evident in the 0-10 cm depth, with the direction of change in the 10-20 cm depth being much more variable. This suggests that under this type of agricultural management, the main changes in bulk density occur in the 0-10 cm depth, with more subtle changes occurring below this depth. The increase in bulk density probably can be partly attributed to soil structural deterioration and movement of fine soil particles into inter-aggregate pore spaces due to raindrop impact, which would decrease soil surface roughness and compact the soil (Simpson and Gumbs, 1986; Barton 1999). The effects of irrigation on soil bulk density were only apparent at the early stage, but few changes were found after just one year. Further investigation will be necessary to identify the effects of irrigation under different cultivation techniques.

4.1.4 Effects of different cultivation techniques on soil penetrometer resistance

Soil penetrometer readings were related to both soil moisture and structure. When soil structure was improved or soil moisture increased, penetrometer readings decreased. The penetration resistance in both tillage treatments was strongly related to soil water content, which depended on rainfall amount (Materechera, 1997). Consequently, the pattern in changes of penetration resistance in the soil during the season generally mirrored soil condition. Some research results stated that minimum tillage could produce significantly higher penetration resistance than traditional tillage. This affected root penetration and distribution, with a lower root length density in the 0-20 cm depths and roots concentrated near the surface, compared with those of conventional tillage (Materechera *et al*., 1997).

In some respects, the penetrometer resistance trends were very similar to the bulk density measurements, but generally the differences between treatments were easier to distinguish. As with bulk density, penetrometer resistance values were different for irrigated and non-irrigated treatments. This suggests that perhaps soil penetrometer resistance is a more sensitive indicator for assessment of changes in topsoil structure and strength than bulk density, as suggested by Simpson and Gumbs (1986).

The Wang Jia data indicate only a relatively small increase in resistance over the season when minimum tillage is applied. However, a large increase in topsoil strength was observed with conventional tillage, especially the no-mulching treatments. This was probably due to continuous exposure to raindrop impact, particularly at the early season when canopy cover was minimal. With straw mulch treatments, there was some additional protection afforded to the soil surface and therefore the increases were slightly lower than conventional tillage. With the polythene mulch treatment, the increase was least. This was probably due to an initially high value, which is attributed to the method by which the polythene mulch is applied. The installation of the mulch requires some soil disturbance, as the strips of polythene are placed around maize plants and had the edges buried into the soil. This may have led to some soil compaction and relatively high penetrometer resistance values at the start of the season. However, during the whole growing season, the disturbance to mulched treatment was less than other remaining treatments, which led to slower increases in resistance values. Such effects on soil penetrometer resistance were also observed by Falayi *et al.* (1979) and Barton (1999). Falayi *et al.* examined the effect of aggregate size and mulching on soil crusting and crop emergence and found that with all aggregate size fractions, crust strength at 50% crop emergence on the mulched plots was lowest, compared to bare control soils.

Minimum tillage had significantly higher penetrometer resistance than the other treatments across the whole plot network at the beginning of the experiment. The same was true at the end of the season, but the difference between treatments had markedly reduced. The absence of any tillage operation before planting led to relatively high topsoil strength, evident from field observations in the form of a hard crust. Similar results on the effect of no-tillage on soil penetrometer resistance were also found by Tollner *et al.* (1984), based on their studies in Georgia, USA. Relating soil bulk density to crust strength, Barley *et al.* (1965) illustrated that the penetration and growth of roots were controlled chiefly by soil strength. Maurya and Lal (1979) observed decreases in total root length with increased penetrometer resistance in a laboratory-based study conducted on sandy clay and loamy sand soils. With both soils, root elongation also decreased with decreasing soil moisture content and increasing bulk density. Barton (1999) observed the same trend on an Ultisol at Yunnan Agricultural University. The results suggested that the initial high crust strength in no-tillage treatment offered some protection from the destructive effects of raindrops.

Polythene mulch prevented raindrop splash compacting the surface and kept surface soil at a higher moisture level, which led to lower penetrometer readings during the whole growth stage. Polythene mulch contributed little to soil structure improvement, but was efficient at maintaining lower resistance and soft structure. Generally, soil resistance with polythene mulch treatment did not increase from 1998 to 1999. Straw mulch was not as efficient at retaining moisture as polythene, but the decayed straw improved soil structure, which led to decreased soil penetrometer readings. The straw mulch, from a long-term view, would probably consistently improve soil structure.

4.1.5 Effects of cultivation technique on soil particle size distribution

Small changes in the primary particle size distribution of the plot soils at Wang Jia were observed over the 1998-1999 period, with a decrease in the median particle size on almost all plots. Generally, there were some changes within the same treatment, but no significant differences between any two treatments in the same year. Over the sampling period, the soil median particle size decreased with time. On conventional tillage and polythene mulch treatments, there were highly significant ($P < 0.001$) decreases in median particle size over the two experimental years. Conventional downslope tillage was the only treatment to have a highly significant decrease in median particle size with both cropping directions. This result could be due to the soil having been exposed to raindrop impact and erosion, suffering more from selective removal of soil fractions. Significant mean differences were found on the straw mulch with contour cultivation, but not on the downslope plot. There were significant differences between minimum tillage, polythene mulch and the other three treatments. This may be due to the surface soil under the straw and polythene mulch being protected from erosion. On the other hand, the protection from the hard crust of the minimum tillage plots may have been sufficient to prevent quantifiable changes in the mean particle size distribution. Similar results were reported by Catt *et al.* (1998) who found that maximising crop cover, using minimal cultivation practises and planting crop rows across rather than up and down the slope, resulted in good structural conditions on arable soil in England.

The particle size incease may relate mainly to the application of manure fertiliser during the four cropping seasons. Much research has indicated that manure is very beneficial for improving soil structure. Lam *et al.* (1997) working in the Shenchong Basin, Deqing County, South China, found that organic fertiliser application improved soil structure and increased soil particle size. The changing of particle size distribution is a long-term procedure, which is influenced by cultivation methods, nutrient use, crop species and soil management. Therefore, further data over more years are required to verify the impact of cultivation techniques on this process.

4.2 Effects of Cultivation Techniques on Soil Chemistry

4.2.1 Effects of cultivation techniques on total nitrogen, phosphorus and potassium (NPK)

With reference to the changes in total N, P and K, the general trend was for total N to increase and total P and K to decrease. The largest increase in total N was in the two straw mulch treatments, although a similar effect was observed on the polythene treatment. One reason may be supplemental nitrogen from decayed straw. Straw mulch may prevent nitrogen leaching and increase total N in a mulch tillage system (Moody *et al.*, 1952). Similar results were found by Liu Zhenyu *et al.* (2000) in Shanxi Province, with total N of 580 ppm under straw mulch compared to 540 ppm under non-mulched plots. Barton (1999) found noticeable increases in total N from two straw mulch treatments compared to the other treatments at Yunnan Agricultural University, using different mulches and planting directions to prevent soil erosion and improve crop production.

Total P decreased on all treatments after two years of cropping (two maize and two wheat seasons). The mulch treatments, including straw and polythene, had lower total P losses compared to conventional tillage, both downslope and contour. These results indicated mulch might be beneficial for maintaining total P on sloping land. This effect is probably related to the function of mulch in decreasing soil erosion, but these effects have not been measured. Many research results have proved that mulch decreases soil erosion. Barton (1999) found straw mulch was very beneficial for decreased runoff and surface soil erosion in Yunnan. Shock *et al.* (1997) found that total P lost after 6 irrigations was 18 kg ha^{-1} from straw mulch and 215 kg ha^{-1} from unmulched furrows. Straw mulch application in irrigation furrows substantially reduced soil erosion and P losses in surface water runoff on a Nyssa silt loam soil in the USA. Selles *et al.* (1997) studied changes in residue management resulting from adoption of conservation tillage systems and found that they had the potential to alter the concentration and distribution of surface P in an Oxisol in southern Brazil. After five years reduced tillage through adoption of minimum tillage or zero tillage practises, increased total P in the surface 10 cm by 15% compared to conventional tillage.

There was no trend or correlation between total K and treatments. There was a general decrease in total K during the two years, especially on conventional tillage with downslope planting having the highest decrease. This was probably due to higher runoff on the downslope cultivation. Barton (1999) found similar results at Yunnan Agricultural University, using different mulching methods during the maize growth season.

4.2.2 Effects of cultivation techniques on available nitrogen, phosphorus and potassium (NPK)

Changes in available NPK were much more variable within treatments, with no significant differences apart from the last sampling data. Therefore, differences are discussed in term of trends. There were greater differences over time. Generally, available N increased, while available P and K exhibited different changes for all treatments. Firstly, available N increased, at different rates, on each treatment, mainly because of the use of manure fertiliser during the four cropping periods. However, compared to the total forms, there were more apparent trends in available N between treatments. An interesting treatment effect occurred with straw mulch, which corresponded to the pattern measured in the total form. The treatment contour planting with straw mulch had the largest measurable increase in available N. This corroborates the notion that applying straw mulch increases reserves of total and available N, through the incorporation and subsequent decay of straw. Similar results were found by Barton at Yunnan Agricultural University, besides decreasing runoff, straw mulch increased available N by 17% compared to traditional downslope tillage (Barton, 1999).

Singh (1995) investigated the effects of wheat residue replacement and chemical fertilizer on microbial biomass, N-mineralization and crop yield in an Indian semi-arid tropical soil with minimum tillage. He found that available N in plots treated with wheat residue was 18-20% higher than control plots and the best method for mulch use was wheat residue plus fertiliser. There was no evidence to suggest that available N decreased under straw mulch, as has been observed by some workers (e.g. Moody *et al.*, 1952). Such decreases can occur where SOM levels are high and mineralisation of N is decreased. This is particularly noticeable with straw residues, due to their high C:N ratio, which can result in net immobilisation of N (Rowell, 1994). In contrast to the straw mulch treatment, available N in conventional tillage downslope treatments increased at a lower rate over the sampling period. A possible explanation is that the decline was observed due to comparatively high runoff and erosion rates, with subsequent removal of available N. Similar trends were observed with other available nutrients. Lin Heping (1998) found the same effect comparing contour to downslope planting in Shanxi Province, China. His results showed that lost available N under contour planting were 61.4 and 56.6% lower than downslope planting on 15 and 20 degree fields, respectively. This was probably one of the reasons contour planting treatments had higher available N compared with downslope planting at Wang Jia.

Available P generally increased on the contour planting and mulch treatment and decreased on traditional downslope tillage over the sampling period. This is contrary to the total P values. In the short-term, available P may increase, particularly through the addition of fertilisers, but total P reserves in the soil can be detrimentally affected. The results showed that there was no correlation between the contents of total and available P. This was also found by Jiang *et al.* (1986), who observed that there was not necessarily a good correlation between the contents of total and available P in Ultisols (Red Soils) in southern China. The highest increase across all plots was evident with the contour cultivated straw mulch. Minimum tillage combined with straw mulch did not show as much effect as contour planting combined with straw mulch treatment. This is probably due to soil compaction in minimum tillage, causing an uneven distribution and higher fixing by soil sediment. Selles *et al.* (1997) observed that under minimum tillage, inorganic P was uniformly distributed within the surface 10 cm of soil. On the other hand, contour planting efficiently maintained available P compared with downslope planting. Straw mulch combined with contour planting had the highest increase over the three-year period. It is possible that, because P is mainly attached to sediments, with very little in soluble form, then losses of P from the straw mulch decreased because of its effectiveness in providing protection from erosion. However, since the same trend was not observed on minimum tillage, further experimental work would be required to verify this explanation. Whether this result arose from the fact that erosion from the downslope plots was generally greater than contoured crops cannot be determined and further observations are necessary.

Available K results were similar to those for N and P in that the highest increase was evident on the minimum tillage combined with straw mulch treatment. Similar to available P, downslope tillage is the only treatment to decrease in available K, while the other four treatments had different ranges of increase. Straw mulch treatments increased available K under contour and minimum tillage. As a labile element, available K was maintained efficiently on the minimum tillage treatment. From the polythene mulch treatment, the increase in available K is higher than no-mulch under the same tillage. It seems that the losses of available K were mainly caused by sediment loss (Barton, 1999). These results again highlight the possible beneficial effects on soil fertility when applying straw mulch. The available K content in these sites for crop growth is classified as <110 ppm (low), 110-120 ppm (medium) and >120 ppm (high) for crop growth (Tang, 1993). The main observation on available K is the apparently marked increase in available K between 1998 and 1999. In 1999, the levels increased markedly for no obvious season (unless there was K in the manure). Beside some cash crops system, such as tobacco, K is rarely applied in other grain crop production systems in the highlands. K has been one of the limiting elements for grain crop production systems in Yunnan.

4.2.3 Effects of cultivation techniques on soil organic matter

Soil organic matter content is one of the most important indexes of soil fertility. It improves soil structure, increases water-holding capacity, increases CEC, decreases Al toxicity, improves tilth and helps nutrient reserves (Fitzpatrick, 1986). Increasing organic matter on the Ultisol, with abundant Al, low pH and cohesive structure, is very beneficial for soil structure. During the whole experimental period, under contour and minimum planting procedures, SOM generally increased on all plots. The largest increases were evident in straw mulch treatments, especially minimum tillage plus contour planting. This may indicate that through the addition of surplus organic material, in the form of either soybean biomass or straw residue, organic matter levels improved. Conversely, the conventional tillage (T+D) generally showed the smallest increases, particularly with downslope cultivation. This may indicate that with possibly higher erosion rates on the conventional tillage plots, SOM was also removed, thereby hindering SOM accumulation (Barton *et al*., 1996). Fan Yongyuan *et al.* (1995) used straw mulch and minimum tillage methods on maize and wheat in Yunnan. They found that minimum tillage combined with straw mulch significantly increased yields by 4.7-5.5% during five years' of planting. Conventional tillage had no significant changes. During the Wang Jia experiment duration, increases were to be expected on all plots, due to the addition of organic manure at the start of the season. However, it is maintenance of SOM levels that is important for soil structural stability and fertility. Therefore, the straw mulch treatments have the advantage that they can both contribute to and maintain SOM levels (Barton, 1999). Even though there were some increases in SOM, there is still a deficiency on the experimental fields compared with optimum levels (low <1.0%, medium 2-3% and high >3%) on Ultisols (Tang Jinchun, 1993). Increasing SOM content is probably the main way to improve the structure of these soils.

4.2.4 Effects of cultivation techniques on soil pH

Soil pH is a fundamental property controlling soil biological and chemical processes, such as biological N fixation, root growth and the mineralisation of organic matter. It is also an indicator of soil acidification, due to acid deposition resulting from industrial processes, or from agricultural activities (Cliff, 1985). Soil pH is a very important factor in plant growth. Generally, the optimum pH value range for plant growth is 5.0-7.5 (Fitzpatrick, 1986), while the best range for maize is 5.5-6.5. It also influences the availability of many other elements in soil (Cliff, 1985). For example, increases in pH could be due to the release of Ca from the single superphosphate fertiliser, a source which can contain 13-20% Ca (Landon, 1994). Yunnan is a multi-soil type province (15 soil types) with different soil characteristics for each soil. Ultisols occupies 65% of the total area (Chen, 1990). According to the Soil Survey, the pH of Yunnan soils is very variable, from 4.0-8.0, but most Ultisols in Yunnan are in the range of 5.0-6.5 (Chen and Hao, 1990). Yunnan soil belongs to the moderately acid soil group, according to the classification of Fitzpatrick (1986). In the long-term, increased soil pH is one of the main agricultural techniques to be demonstrated to farmers by agricultural researchers in Yunnan. From the results of two crop seasons, pH in each treatment increased ~0.05-0.10 units. This increase is probably because of the use of manure fertiliser during the two planting seasons. The increases were very significant, especially the straw mulch treatments. It is suggested that the decayed straw increased the organic fraction, which is beneficial to increase soil CEC and helps to improve soil structure (Fitzpatrick, 1986). In a long-term sustainable agricultural view, mulch straw is a very useful method to improve the acid soils of Yunnan and enhance the release of other necessary elements, such as P. Total P in Yunnan soil is very high, but available P is very low, at the low soil pH. Although most minerals and nutrients are more soluble or available in acid soils than in neutral or slightly alkaline soils, P is never readily soluble in the soil, but is most available in soil with pH ~6.5 (Sun Shutang, 1990). When pH is <6.5, there can be high concentrations of soluble Al, Fe and Mn, which may be toxic for some plants (Sun Shutang, 1990). The research results suggest that balancing soil nutrient content using straw mulch is a beneficial management method on upland fields in Yunnan.

4.2.5 Effects of cultivation techniques on other nutrients

To produce optimum yields, all crops must have an adequate supply of all 16 essential plant nutrients. If one or more is lacking in the soil, crop yields may be decreased, even though adequate amounts of the other nutrients are available (Cliff and Thompson, 1996). The exchangeable Ca and Mg results indicated maize concentrations increased over the sampling period on most treatments. This does not mean the effects of these elements are less important to the crop, but just the amount needed is less than NPK. Although trace elements in fertilisers are used for some cash crops, such as tobacco, their use for large scale crop production has not been implemented in Yunnan. From the results of different years of samples from Wang Jia, some changes under different treatments can be identified. Traditional tillage, treatments T+D and T+C, had increased Ca concentrations, while others did not change. After a cropping season, all treatments had decreased S, while the straw mulch treatments maintained relatively higher levels than other treatments. Furthermore, S is applied in Super-phosphate fertiliser used as base fertiliser in Yunnan crop planting procedures. However, the farms rarely use Super-phosphate fertiliser during planting maize. S probably becomes one of the elements limiting maize productivity in the uplands.

Concentrations of Zn decreased on the contour and downslope cultivation areas while in minimum tillage and polythene mulch treatments Zn increased during the two cropping years. This is also probably the main reason for the occasional Zn deficiency in the Yunnan uplands (Jiang, 1990). The decrease in Zn was probably due to loss with the higher runoff on uplands in traditional tillage (Barton 1999). For other trace elements, there were also some changes after two years of experiments. The appropriate application rates of trace element fertiliser need further investigation as part of a sustainable agricultural fertiliser system.

4.3 Effects of Cultivation Techniques on Crop Development and Yield

Crop yield is a result of a combination of synthetic factors, including weather, soil and management acting on the crop genotype. In both years, treatment effects were apparent on both the growth and yield of maize. Because no irrigation was supplied in 1998, the yields were generally lower under each treatment compared with 1999, when irrigation was applied during early maize growth stage. Therefore, maize plants were less likely to have undergone periods of stress in 1999, compared to the 1998 season, when rainfall distribution was much more variable. The critical period over which this had the greatest effect was shortly after planting in 1998, when problems with seed germination and early maize growth were experienced across the plot network. The results of plant height, Leaf Area Index and Green Leaf Area Duration confirmed field observations of significant differences between treatments, both in 1998 and 1999. Further confirmations of the treatment effects were evident from the yield data. Therefore, according to the performance of maize under different cultivation techniques, based on the results from this study, suitable treatments for the uplands of Yunnan may be evaluated.

4.3.1 Effects of polythene mulch on maize growth components and yield

The effects of polythene mulch are usually explained in that the clear polythene allows radiation through to the soil, but the heat is then trapped beneath the polythene and consequently, soil temperatures increase substantially. This occurred because increased soil temperature enabled the crop to more rapidly attain maximum Green Leaf Area Index. Polythene also reduced evaporation, thereby maintaining higher soil moisture contents than other treatments. The beneficial effects of contour cultivation combined with polythene mulch on crop growth were very significant both in 1998 and 1999 at Wang Jia. Plant height of T+C+P increased significantly quicker than other cultivation methods at the early growth stage in both the 1998 and 1999 seasons. Green Leaf Area Index (GLAI) and Green Leaf Area Duration (GLAD) define an important structural property of a plant canopy, the number of equivalent layers of leaves the vegetation displays relative to a unit ground area. GLAI most directly quantifies plant canopy structure, being highly related to a variety of canopy processes, such as water interception, evaporation, photosynthesis, respiration and leaf litter fall. GLAD indicates the total interception capacity of the canopy and is a good indicator of final yield. With maize development results, one of the clearest trends observed from the two field seasons was the effect of polythene mulch. In 1998, the differences in plant height and Green Leaf Area Index were distinct compared with the other four treatments. During 70-100 days after sowing there were no significant differences in GLAI between treatments. By day 100 polythene mulch treatments still had higher GLAI values than other treatments. Polythene mulch maintained a green canopy for longer.

Both 1998 and 1999 results show that the influences tended to decline through the season. Periodic monitoring of both soil temperature and soil moisture throughout both seasons, in conjunction with the plant height and leaf area index curves, suggested that the beneficial influence of the mulch was most effective within 50 days after sowing. Such effects were primarily in response to maize development, whereby at the start of the season, there was maximum treatment effect due to low percentage canopy cover. It was during this time that clear differences between the polythene mulch and the other four treatments were evident. As the crop developed and the surface become increasingly shaded, the effectiveness of mulch diminished and the difference between treatments decreased. This was similar to results on maize growth from a study in North Dakota (Willis *et al.*, 1963) and in Yunnan (Barton, 1999), where plant height, GLAI, differences between polythene mulch and non-mulch practise diminished through the season.

The effects of the contour cultivation plus polythene mulch on maize grain yield were equally marked, but again were more evident in the 1999 season when irrigation was available at the early growth stage. Greater stress was exerted on the maize plants on the non-irrigated plots. The highest yields on Wang Jia Catchment, with few exceptions, were always from the contour cultivation combined with polythene mulch treatment. Therefore, the beneficial influence of the T+C+P treatment not only manifests itself in maize development, but also significantly influences final biomass and grain yield. The grain yields were 8.4 and 10.8 t ha^{-1} for 1998 and 1999, respectively. These represent 50.0 and 61.1% increases compared with the control and 100.0 and 163.4%, respectively, of the mean maize yield of all China in 1998 (China State Statistics Bureau, 1999). When comparing the mean maize yield in Yunnan, increases in yield were even more remarkable. Compared with the mean maize yield of all Yunnan Province of 3.85 t ha^{-1}, there were 1.5 and 2.8 fold increases in 1998 and 1999, respectively (Yunnan Provincial Yearbook, 1999).

4.3.2 Effects of straw mulch on maize growth components and yield

The benefits of straw mulch are brought about by several factors, including reduced evaporative losses and greater infiltration, due to maintenance of topsoil structure and prevention of surface crusting from raindrop impact. Straw mulch also maintained higher nocturnal temperatures, by decreasing heat losses and this was probably beneficial for plant development.

Straw mulch was more effective under non-irrigation than irrigation. When there was enough soil moisture after irrigation, the prevention of evaporation appeared less important for crop growth during the early spring dry season in Yunnan. When there was no irrigation, straw mulch was very useful method for conserving moisture left in the soil and was therefore beneficial to final crop yield.

The effects of straw mulch were observed primarily at the early stage. To a certain degree, straw mulch increased GLAI in the early growth stage as part of promotion of seedling development, which increased GLAD. When irrigation was supplied, as in 1999, straw mulch did not show significant benefits for GLAI and plant growth compared with no mulch.

Beneficial effects on maize yield from applying straw mulch were observed in both years. Although yields were not as high as achieved under the contour plus polythene treatment, they were still noticeably greater for the treatments of T+C+St and M+C+St with 16.8 and 19.8% higher yields, respectively, than those achieved with downslope cultivation (control) in 1998. Similar effects were found with 24.1 and 20.4% in the non-irrigated experiment the 1999. Such effects with straw mulch have been observed elsewhere (e.g. Moody *et al.*, 1963; Lal, 1974; Tang and Zhang, 1996; Barton, 1999; Liu Zhenyu, 2000), whereby increased yields have been attributed to changes either in soil temperature or soil moisture regimes. Aina (1981) advocated early mulching based on experiments conducted on a sandy loam in Nigeria. Maize yields were higher compared to no-mulch, which the author attributed to relatively lower soil temperatures and higher soil moisture levels during dry and hot weather conditions, improving plant growth, leaf area index and root development.

Considering the influence of mulch on soil moisture, there appeared to be a positive effect throughout the season, where it either ranked second, next to the polythene mulch, or exceeded the polythene mulch value. Seasonal means for 1998 and 1999 were little different to the polythene mulch values, equal to 15.9 and 19.1%, respectively, compared to 15.4 and 18.8% with polythene mulch. Especially, when there was sufficient soil moisture during early spring, the effect of straw on maintaining the limited moisture reserves was significantly more efficient than any other treatment.

There have been many similar research results concerning straw mulch. Simpson and Gumbs (1986) found beneficial effects of applying straw mulch over conventional tillage without mulch in their study on a heavy clay soil in Guyana. Mulched plots had higher soil moisture content at both the 0-15 and 15-30 cm depths compared to the unmulched plots. This was particularly beneficial during drought stress periods, when soil moisture was kept within the available range for plant growth. Barton (1999) found an absolute mean of 3.3% more soil moisture content under straw mulch over polythene during the whole maize growth season in Yunnan. Rathore *et al.* (1998) observed that straw mulch conserved more water in the soil profile during the early growth period compared to no-mulch. Therefore, straw mulch may be used to achieve higher water use efficiency in semi-arid and sub-tropical regions (Gajri *et al.*, 1997), as well as in Yunnan upland fields, where spring drought exists. However, they noted that the effects depended on the amount and distribution of rainfall, since under conditions of high rainfall over long periods, soil saturation can be increased. This is due to the heavy nature of the soils and reduced evaporation beneath the mulch, which can hinder plant development.

Given the data available, it is not possible to ascertain whether changes in temperature or moisture were more important in evaluating the role of straw mulch. When considering the factors influencing maize growth, rainfall regime, field topography and management require evaluation. It is possible that the benefits of straw mulch are predominantly evident when periods of moisture stress occur at critical times of crop growth, as occurred in the non-irrigation experiment in 1999. Further work over consecutive seasons need to be conducted to substantiate this hypothesis.

4.3.3 Effects of different tillage methods on maize growth components and yield

As with the straw mulch treatment, results from the minimum tillage plots on crop development and yield were variable. Yields tended to be higher than the conventional tillage plots (T+D), but lower than conventional tillage with contour planting. This was probably because the compact surface soil contained less soil moisture, which influenced maize root growth. In 1999, minimum tillage had a noticeably increased yield under irrigated conditions. It indicated that when there is enough water supplies (including rainfall and irrigation), minimum tillage is beneficial for maize growth and can lead to higher yields. Lal (1995) also reported higher yields under no-tillage compared with conventional tillage on a Nigerian Alfisol. Mean maize grain yields over 17 consecutive seasons were 2.69 and 2.23 t ha^{-1} with no-tillage and conventional tillage, respectively, in the first growing season, and 0.88 (no-tillage) an 0.74 t ha^{-1} (conventional tillage) in the second season. Lal (1995) also noted that applications of fertiliser or mulch in combination with the no-tillage system increased grain yields.

Without mulching, conventional tillage generally performed poorest out of the five treatments, both in terms of crop development and final grain yield. Both crop growth in 1998 and 1999 were especially slow, with subsequent grain yields for downslope cultivation being only 4.57 and 6.74 t ha^{-1}, respectively, compared to equivalent values of 5.76 and 10.78 t ha^{-1} with polythene mulch. The poor performance may actually relate to water availability within the topsoil, since the lowest seasonal mean soil moisture content occurred with the conventional tillage treatment during early stages. Another probable reason was the high runoff decreasing available nutrition, which caused a thin and poor topsoil on conventional tillage (Barton, 1999). Hergert *et al.* (1993) found that minimum tillage cropping systems and limited irrigation have possibilities for maintaining acceptable maize yields, winter wheat and soybean in areas of declining irrigation water in North Platte, The Netherlands. Stockfisch *et al.* (1999) found organic matter stratification and accumulation, as a result of long-term minimum tillage, were completely lost by a single application of conventional tillage after 20 years in Lower Saxony, Germany.

4.3.4 Effects of planting direction on maize growth components and yield

Cropping direction effects, although varying with the different surface treatments, were apparent from the plot data. Much research indicates that the main effects of contour planting are decreased runoff, maintenance of nutrients and increased penetration of sunlight, leading to higher crop yield (Dong Pingya, 1993). Barton (1999) found from research compared out between 1993-1996 in Yunnan Agricultural University (YAU) that contour cultivation erosion rate was 0.69 of the mean downslope orientated cultivation rate. Liu (1991) and Barton (1999) also found greater effectiveness with contour cultivation. Contour planting reductions in soil loss and runoff were observed by Narayana (1987) at Dehra Dun, India, where runoff and erosion were 74 and 71% of the downslope values, respectively.

Although data on the effectiveness of contour cultivation on runoff were not available at Wang Jia Catchment, there were some properties, such as nutrient, showing relative differences. There were 9.6 and 4.2% higher total N and P and 28, 25.7 and 77% higher available NPK on contour compared with downslope planting. Similar results were found by Kukal *et al.* (1993) on arable lands of submontane Punjab, India. They stated that contour cultivation reduced soil loss from 6.3 to 2.9 t ha^{-1}, compared to slope cultivation. On sloping lands contour bunding (embankments) decreased soil loss from 2.56 to 0.59 t ha^{-1} and increased wheat yields >20% because of higher nutrient retention after bunding.

During two years of planting, according to the results of soil particle analysis, downslope treatments had a 15.8% increase in sand content compared with contour planting at Wang Jia. This indicated that much clay and silt had been lost in runoff. Shipitalo *et al.* (1998) also found such phenomena at Coshocton, Ohio, USA. They stated that by tilling and planting on the contour and increasing fertility levels, soil loss was reduced more than three-fold. They accounted for 84% of the variation in mean sediment concentration from the downslope treatments, but only 62% of the variation in mean sediment concentration from the contour treatments on a Tama silt loam soil (McIsaac *et al.*, 1990). However, there was little evidence from the Wang Jia study to indicate that erosion or runoff was decreased by contour cultivation, thus more research work is needed at the large-scale in Wang Jia Catchment.

Considering planting direction effects on maize yield, there was a clear difference between downslope and contour planting, based on the two cropping seasons. For easy operation, farmers in the Yunnan uplands often cultivate and plant using the downslope method. This action caused a loss of maize yield of 590-740 kg ha^{-1} every year. If calculating yields based on the research data of Wang Jia and the total planting area of Yunnan, there will be some 50,000-70,000 tonnes increased maize yield by just adopting contour planting methods in the Yunnan highlands. Furthermore, this method is a very easy agricultural procedure and there were few extra labour costs during operations.

4.3.5 Effects of irrigation on maize growth components and yield

As described previously, spring drought is the most important limiting phenomenon, often causing crop planting to miss the optimum season and producing poor germination conditions, even when maize is planted on time. Increasing the irrigation area has been one of the major measures implemented by the Yunnan Provincial Government to improve crop productivity. Due to the uneven economic development in the Yunnan uplands, 95% of Yunnan hilly fields still lack irrigation.

The main effect of irrigation systems is to reduce drought risk, thus ensuring a stable crop yield, even during dry seasons. From 1999 data, it was found all soil and crop parameters, as well as yields from the irrigated and non-irrigated treatments, were noticeably different in 1999, even with just two irrigations. During 1999, there was drought in June and July, the monthly mean air temperature was 0.9^0C higher than 1998 and the rainfall was 128.3 mm less in the same period compared to 1998. Irrigation met water requirements and assisted crop growth. Even just three litres of water supplied to each pit had significant effects compared with a similar experiment where no irrigation was applied. Soil moisture was 5.5, 5.5, 4.8, 5.0 and 6.4% higher, respectively, than non-irrigation with treatments T+D, T+C, T+C+St, M+C+St and T+C+P during the early growth stage (55 days after sowing). Meanwhile, other parameters were improved by irrigation during the dry season (Chapter 3). The final yields were 15.5, 10.9, 12.5, 0.6 and 32.4% higher, respectively, than the same non-irrigated treatments. There are many similar research reports, which show similar results. Drimba (1997) documented that irrigation ensured the achievement of a given yield at minimum risk at the experimental nursery of Debrecen Agricultural University, Hungary, between 1990-1993. Gill *et al.* (1996) studied the effects of tillage, mulching and irrigation on maize (*Zea mays* L.) yield on a loamy sand (mixed, hyperthermic, Typic Ustipsamment) for early (high evaporativity) and normally sown (relatively low evaporativity) crop in a semi-arid sub-tropical monsoon region at Punjab Agricultural University, Ludhiana, India. They found that irrigation combined with mulch increased grain yield by 1.6 t ha^{-1} for the early season and 0.5 t ha^{-1} for the normal season crop over the yield of 2.0 t ha^{-1} achieved with conventional tillage, regardless of season. Crop response to tillage and mulching was generally linked to the interplay between water supply (rain + irrigation) and demand (seasonal evaporativity) during the growing season. Increasing irrigation frequency increased crop yield when evaporation exceeded rainfall early in the growing season.

The importance of irrigation was very clear in upland crop production. The most important consideration is the initial investment cost. According to the assessment, irrigation system establishment investment returns costs in 4-5 years under proper management. Wang Hongzhong *et al.* (1999) assessed the investment and the economic return rate of water ponds in Yunnan. They documented that 150 m^3 of pond water were needed per one hectare field. Generally, the water pond can last at least 20 years under proper maintenance. The irrigation from the pond increased yield by 1.5 t ha^{-1} per year, so the investment cost could be returned during 4.5 years. Whenever established, it will help to reduce the occasional drought and ensure stable crop yields. It is very important for upland farmers to implement a sustainable and productive cropping system and this is encouraged by the local government.

4.4 Conclusions

The main aim of this research project was to quantitatively assess the effectiveness of several practical cultivation methods which could be utilised on sloping land in the highlands of Yunnan Province. There have been few experiments carried out to assess conservation measures in relation to productivity effects in upland agriculture in Yunnan Province. Research has concentrated on just some aspects. Although many of the effects described are significant, they are based on just two years of fieldwork, so only short-term conclusions can be drawn.

1) Contour planting

   The results suggested contour planting is a useful method. It is easily operated and effective for soil and nutrient conservation (based on other data) and can significantly increase crop yields in upland agricultural systems.

2) Minimum tillage

   Minimum tillage is a useful method to maintain soil structure. It is beneficial for nutrient retention and maintains higher soil moisture content than conventional downslope tillage. When combined with straw mulch, it can efficiently reduce drought risk during early spring in the monsoonal climatic conditions. Without contour planting, it may not lead to increased yields.

3) Straw mulch

Straw mulch is a very effective soil and water conservation method, even on steep slopes (based on erosion plot data). Ground-level mulch protects the soil surface from raindrop detachment and, through maintenance of soil structural stability, encourages infiltration. Straw mulch reduces evaporation and maintains higher soil moisture contents during the dry season. Soil moisture was 3.0-4.5% higher than unmulched treatments during the dry spring. Grain yields were significantly higher when applied with contour planting compared with unmulched downslope techniques.

4) Polythene mulch

Compared to downslope planting, contour planting with polythene mulch promoted crop growth and led to increased grain yield. The effects included:

A) Increased GLAI throughout the season, resulting in a higher GLAD.
B) Increases in shoot height by the end of the growing season.
C) Significant increases in total standing biomass and stem dry weights.
D) Significant mean yield increases by 32.5 and 51.6% in grain yield based on plot data, compared with the control (T + D) in 1998 and 1999, respectively.

The promotion of growth and yield appeared to be associated with the higher surface soil temperatures under polythene mulch, particularly early in the season. The results suggest that contour cultivation plus polythene mulch increases dry matter production and yield by increasing soil temperature, promoting early vegetative growth leading to higher GLAI, greater light interception and corresponding increases in assimilation. The role of soil moisture depends on the rainfall at the time polythene is applied. If rainfall is low, the soil will be dry and the polythene cover may not be beneficial. Therefore, irrigation combined with polythene mulch could be very effective in retaining higher levels of soil moisture. As in 1999, this could produce very substantial increases in yield when water is limiting.

5) Irrigation

Irrigation is very important for good crop establishment and early season growth in Yunnan Province, when the monsoon rains are late or unreliable, producing a spring drought. In separate experiments in 1999, with a low rainfall in June, irrigated plots with polythene mulch gave 23% higher yield than non-irrigated plots with the same treatment.

6) The costs-benefit analysis

The cost-benefit analysis results showed that contour planting and mulching (straw and polythene) were valuable for increasing maize production. Irrigation was beneficial for early growth and led to higher crop yield, than non-irrigation and the investment can be returned after 4-5 years.

Therefore, polythene mulch combined with irrigation was the best treatment for improving productivity, while straw mulch was most effective for soil property improvement. Combining the field data from Wang Jia with the erosion plot data from YAU (Barton, 1999), suggests downslope cultivation should be strongly discouraged. It is the least effective treatment in term of soil conservation and produces the lowest yields. In terms of evaluating agricultural systems, the research results clearly showed the merits and limitations of different cultivation, planting direction and mulching methods. Apart from conventional downslope cultivation, the other four treatments have their own advantages, which may be important in different circumstances. In terms of achieving more sustainable and productive cropping systems in Yunnan Province, contour planting plus straw mulch is likely to be the most effective in maintaining good soil characteristics and high yields when fertilisers are applied. Polythene mulch will be particularly effective in seasons with spring drought where irrigation is available. The sustainability of this technique together with the use of irrigation requires further consideration. The upland area accessible to irrigation is still very small. It is hoped the data provided in this thesis will contribute to the growing body of knowledge on more sustainable agricultural systems in Yunnan Province. The research has highlighted several important issues related to both existing and potential sustainable crop measures and has provided a baseline of data to be utilised in the continuation of the collaborative research programme in Wang Jia. It is anticipated that the results of this and future research will be of considerable interest to those involved in the management of crop production in Yunnan Province and throughout the highlands of South-East Asia.

4.5 Critical Evaluation of Research Methods

There are several areas of work undertaken in this study that could have been improved and these should be considered in developing future research:

1) The experimental design can be improved by adding more treatments and/or blocks. This could contribute traditional tillage combined with different mulches and minimum tillage with bare soil or polythene mulch. This would have allowed more statistical analyses to be conducted and would have improved the reliability of the observed treatment differences.

2) The design of the plots themselves could have been improved. For example, the buffer zones between plots would have been more effective had similar cultivation and planting around each plot been possible, rather than planted by the farmers themselves using different maize cultivars. Planting should aim to minimise the edge effects from relatively small plots

3) Because of the limitation of field size and slopes, different treatment plots had slightly different slope gradients, which may have caused differences in water and nutrient distributions. If it had been possible, larger plot sizes would have been used with steeper and more consistent gradients. This is one of the unavoidable disadvantages of using this particular field site.

4) Research concentrated more on crop productivity, rather than soil and water conservation. No facilities were established as part of a large strategy for catchment studies to collect runoff from different treatments. It was impractical to estimate the runoff and the losses of nutrients from surface and tillage treatment methods.

5) The comparison of irrigation treatments was limited because two different locations in the Catchment were used. Other differences (e.g. soil type) could have influenced crop responses. Direct statistical comparisons were not possible.

6) The weather station was 0.5 km from the experimental site and 200 m lower. There may have been some variations in the weather between the weather station and the experimental site.

4.6 Suggestions for Future Research

The limitations of the present research have been discussed above, and as this field area is still used as part of an on-going research programme, the following recommendations and comments are to aid future work:

1. More detailed study of polythene and straw mulch, both separately and combined, is required to discover whether soil moisture or soil temperature effects are more important. This should be linked to more detailed monitoring of weather. The problem here is that crop response is very season dependent and also dependent on how irrigation is used. In an extended experiment, replicated irrigation comparisons could be carried in the same experimental area, not in separate locations.

2. The effects of the treatments on soil loss and runoff could be explored further by establishing soil pits on the slope. However, this would alter the degree of participation by local farmers. The contribution to soil conservation in Wang Jia needs to be quantified. Also, different soil types and slopes in the Catchment could be tested, to evaluate effectiveness in several agricultural situations.

3. Polythene and straw treatments could be combined in future experiments to evaluate if their separate advantages would produce any synergistic effects. The other treatments were less effective and may not justify further work. However, there is a problem in proposing widespread use of polythene as part of more sustainable cropping systems.

4. The results from this research have identified general trends in the effectiveness of several treatments for sustainability in upland agriculture. Since the experiment at Wang Jia demonstrated significant and substantial yield benefits, these need to be translated into economic returns (inputs versus outputs) and than discussed with farmers. The socio-economic benefits need to be assessed to establish the sustainability of the polythene and straw mulch treatments and estimate their acceptability to farmers. It is also very important to more fully investigate over what slope angle these techniques could be recommended. Above a certain slope, it may be difficult to justify continuing arable cultivation, as the long-term effects of intensive production are unlikely to be beneficial. Maintaining this level of production is also an issue in sustainability terms, because of the relatively high inputs of fertilisers.

5. Long-term productive use of land is the aim of more sustainable agriculture. Erosion on the polythene mulch treatment occurred mainly where there was no polythene. A suitable crop planted between the rows could efficiently decrease surface runoff. Intercropping between the polythene maybe an effective way to decrease runoff and nutrients losses.

6. Soil sample collection and analysis could be improved. A strict soil sampling programme should be maintained in order to build up a comprehensive data set on soil properties. Soil sample analyses need to use the standard methods and analysed as quickly as possible, to prevent the loss of available N. Thus data could be more accurate and help to explain the changing nutrient states under different treatments. Furthermore, a two-year programme is too short to monitor important changes in soil nutrients and structure.

7. Establishing a weather station at the experimental site is very important. The local weather station was mainly recorded manually at 0900 local time. If an automatic record weather station was established at the experimental site, the climatic data could be more complete and reliable. It is very important to use more seasons with closer monitoring of both the canopy performance and the soil characteristics at different depths. In this way, it will be possible to not only offer detailed experiments of how the different techniques achieve improved productivity, but

also determine how the cropping strategies could be optimised in different seasons.

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Appendix 1.1 Mean soil temperature measurement at Wang Jia in 1998 (n = 5) ^{o}C

Measurement time		0730-0830					1330-1430					1730-1830				
Date	Treatment	Soil depth (cm)					Soil depth (cm)					Soil depth (cm)				
		0	5	10	15	20	0	5	10	15	20	0	5	10	15	20
20/06	T+D	14.7	16.6	17.9	19.0	19.7	23.6	22.6	20.4	19.9	19.9	19.6	22.1	22.5	21.7	21.1
	T+C	15.7	16.4	17.4	18.3	19.0	29.5	25.5	21.7	20.6	19.9	18.1	20.5	21.8	21.5	21.1
	T+C+St	15.8	16.4	17.3	18.1	18.7	28.5	25.3	21.6	20.2	20.0	17.6	20.1	21.4	21.3	20.8
	M+C+St	15.4	16.2	17.4	18.5	19.1	29.8	24.9	21.4	20.3	19.9	18.5	21.0	21.7	21.2	20.8
	T+C+P	16.2	17.8	19.1	19.8	20.4	34.9	29.7	25.6	22.0	21.7	23.5	25.5	25.2	24.1	23.2
10/07	T+D	17.7	18.4	18.7	19.1	19.2	21.9	21.8	21.4	21.0	20.8	23.9	23.5	22.9	22.6	22.6
	T+C	18.7	19.1	19.4	19.4	19.4	22.1	22.0	21.4	21.2	20.9	24.8	24.4	23.3	23.3	23.1
	T+C+St	18.3	18.9	19.2	19.3	19.3	20.7	21.1	20.7	20.5	20.3	23.4	22.6	21.8	21.6	21.4
	M+C+St	18.7	19.0	19.1	19.3	19.5	21.5	21.3	21.0	20.6	20.4	23.6	23.3	22.8	22.7	22.6
	T+C+P	18.7	18.9	19.0	19.1	19.3	21.2	21.3	21.0	20.5	20.3	23.1	22.2	21.6	21.4	21.4
31/07	T+D	19.2	19.6	20.0	20.2	20.2	21.5	19.6	20.3	20.4	20.5	21.1	21.1	20.8	20.6	20.8
	T+C	19.2	19.5	20.1	20.4	20.5	21.1	19.5	20.5	20.5	20.6	21.5	21.3	20.9	20.9	20.9
	T+C+St	19.5	19.8	20.2	20.5	20.6	21.1	19.8	20.6	20.6	20.8	21.6	21.4	21.1	21.1	19.3
	M+C+St	19.3	19.7	20.2	20.5	20.7	20.9	19.7	20.6	20.6	20.7	21.4	21.2	21.0	21.0	21.1
	T+C+P	19.4	19.7	20.1	20.3	20.4	21.2	19.7	20.6	20.6	20.7	21.3	21.2	21.0	20.8	20.9
20/08	T+D	18.0	18.1	19.2	19.7	19.4	29.4	26.8	24.2	23.2	20.4	25.2	25.9	25.6	24.6	20.8
	T+C	18.6	18.5	19.4	19.9	19.0	29.3	26.4	24.2	21.2	19.6	24.4	25.1	23.7	22.9	20.9
	T+C+St	18.2	18.1	19.4	19.8	19.3	30.1	25.1	23.0	21.1	19.6	23.2	22.9	22.3	21.7	19.3
	M+C+St	18.3	18.1	19.1	19.6	19.2	26.5	23.8	22.5	20.9	19.8	24.0	23.1	22.2	21.2	21.1
	T+C+P	18.9	18.6	20.0	19.5	19.3	28.7	23.9	22.7	21.1	20.3	25.5	25.8	25.1	24.6	20.9
20/09	T+D	18.4	18.5	18.7	18.9	19.1	22.3	22.2	21.4	21.3	21.3	22.9	22.5	22.8	22.3	21.8
	T+C	18.7	18.8	19.0	18.9	19.2	21.7	21.3	20.8	20.9	20.9	21.9	21.6	21.5	21.4	21.3
	T+C+St	19.1	18.9	19.0	19.2	19.3	22.9	22.6	22.1	21.5	22.0	22.7	22.7	22.2	21.8	21.6
	M+C+St	19.2	19.2	19.2	19.4	19.6	17.9	17.9	20.3	17.6	17.6	23.1	22.9	22.4	22.1	21.9
	T+C+P	19.0	19.2	19.4	19.5	19.7	22.6	22.4	22.0	21.7	21.5	23.5	23.4	22.6	22.3	21.7

Appendix 1.2 Mean Soil Moisture Measurement (% by weight) at Wang Jia in 1998

Date		20/06/98			10/07/98			29/07/98			20/08/98			20/09/98		
Treatment	Block	Soil depth (cm)			Soil depth (cm)			Soil depth (cm)			Soil depth (cm)			Soil depth (cm)		
		0-5	5-10	10-15	0-5	5-10	10-15	0-5	5-10	10-15	0-5	5-10	10-15	0-5	5-10	10-15
T+D	A	14.97	15.85	15.39	17.19	18.80	16.46	15.74	14.37	15.93	17.91	18.24	18.10	13.11	12.14	11.99
	B	16.11	15.13	15.58	15.52	15.60	16.98	14.75	14.26	14.83	16.37	17.61	17.07	14.25	11.36	12.33
	C	14.67	15.02	15.19	17.35	17.62	15.20	14.64	14.85	14.82	14.26	18.20	17.99	13.85	12.96	13.02
	Mean	**15.25**	**15.33**	**15.39**	**16.69**	**17.34**	**16.21**	**15.04**	**14.49**	**15.20**	**16.18**	**18.02**	**17.72**	**13.74**	**12.16**	**12.45**
T+C	A	16.05	16.40	16.94	18.12	18.44	18.95	16.80	15.33	17.20	19.35	19.95	20.22	14.60	15.68	15.51
	B	15.18	16.41	14.87	16.73	18.64	16.80	15.94	16.50	16.36	16.89	18.21	17.59	12.35	12.25	12.40
	C	14.75	16.43	14.76	15.32	14.94	16.78	15.27	15.97	14.93	14.83	18.58	18.43	12.30	11.83	13.42
	Mean	**15.33**	**16.41**	**15.52**	**16.72**	**17.34**	**17.51**	**16.00**	**15.93**	**16.16**	**17.02**	**18.91**	**18.75**	**13.08**	**13.25**	**13.77**
T+C+St	A	13.07	13.05	12.76	16.84	16.79	17.84	16.51	15.51	16.37	16.78	19.33	22.33	12.81	13.95	15.63
	B	17.31	15.78	17.09	18.66	17.23	18.54	17.34	17.39	17.67	18.12	19.77	17.90	11.88	14.14	14.45
	C	14.65	15.87	16.35	17.85	18.76	15.57	15.43	15.05	15.70	15.34	16.75	18.12	19.73	13.22	14.17
	Mean	**15.01**	**14.90**	**15.40**	**17.78**	**17.59**	**17.32**	**16.43**	**15.98**	**16.58**	**16.75**	**18.61**	**19.45**	**14.81**	**13.77**	**14.75**
M+C+St	A	18.00	18.12	17.36	19.39	19.05	17.69	17.86	17.24	16.77	19.73	21.97	20.11	15.25	13.70	15.48
	B	16.51	15.47	16.97	17.36	18.33	17.84	14.48	15.03	15.71	16.58	14.54	17.59	14.38	13.41	13.34
	C	16.44	16.26	16.01	18.15	18.30	15.75	16.40	17.59	16.57	17.56	19.66	19.68	14.32	13.71	13.57
	Mean	**16.98**	**16.62**	**16.78**	**18.30**	**18.56**	**17.09**	**16.25**	**16.62**	**16.35**	**17.95**	**18.73**	**19.13**	**14.65**	**13.61**	**14.13**
T+C+P	A	15.83	17.42	16.28	16.63	16.16	16.18	15.52	15.26	16.55	19.09	19.28	19.62	13.36	14.26	14.01
	B	17.69	14.77	14.73	19.80	19.93	17.33	15.43	15.14	16.27	17.56	18.82	19.00	15.48	15.52	16.38
	C	13.38	13.84	13.33	16.74	15.34	18.46	14.77	14.53	14.59	15.26	18.19	17.13	13.48	12.49	13.46
	Mean	**15.63**	**15.34**	**14.78**	**17.72**	**17.15**	**17.32**	**15.24**	**14.98**	**15.80**	**17.30**	**18.77**	**18.59**	**14.11**	**14.09**	**14.61**

Appendix 1.3 Mean Soil Bulk Density Measurements at Wang Jia in 1998

Block	Treatment	Depth (cm)	Measurement date 04/06/98 Bulk density (g cm^{-3})	25/08/98 Bulk density (g cm^{-3})	02/10/98 Bulk density (g cm^{-3})
A	T+D	0-10	1.202	1.238	1.338
		10-20	1.250	1.287	1.307
	T+C	0-10	1.263	1.298	1.308
		10-20	1.222	1.277	1.327
	T+C+St	0-10	1.275	1.293	1.393
		10-20	1.151	1.251	1.351
	M+C+St	0-10	1.327	1.385	1.395
		10-20	1.384	1.392	1.432
	T+C+P	0-10	1.234	1.277	1.307
		10-20	1.173	1.275	1.276
B	T+D	0-10	1.298	1.304	1.364
		10-20	1.328	1.351	1.358
	T+C	0-10	1.273	1.303	1.323
		10-20	1.214	1.256	1.286
	T+C+St	0-10	1.298	1.319	1.359
		10-20	1.296	1.332	1.332
	M+C+St	0-10	1.443	1.486	1.579
		10-20	1.338	1.344	1.354
	T+C+P	0-10	1.154	1.191	1.211
		10-20	1.231	1.309	1.369

C	**T+D**	0-10	1.298	1.314	1.330
		10-20	1.296	1.297	1.318
	T+C	0-10	1.259	1.385	1.485
		10-20	1.217	1.333	1.433
	T+C+St	0-10	1.209	1.308	1.388
		10-20	1.237	1.304	1.404
	M+C+St	0-10	1.298	1.325	1.345
		10-20	1.296	1.324	1.334
	T+C+P	0-10	1.255	1.270	1.290
		10-20	1.286	1.292	1.319

Appendix 1.4 Soil Penetrometer (kg cm^{-2}) readings at Wang Jia in 1998

		15/06/98			15/06/98			15/06/98		
Treatment	No.	Block			Block			Block		
		A	B	C	A	B	C	A	B	C
T+D	1	0.021	0.021	0.022	0.024	0.023	0.032	0.032	0.032	0.039
	2	0.022	0.018	0.022	0.023	0.032	0.031	0.030	0.036	0.032
	3	0.024	0.022	0.02	0.024	0.023	0.024	0.039	0.038	0.033
	4	0.019	0.021	0.023	0.024	0.031	0.024	0.038	0.031	0.031
	5	0.021	0.022	0.023	0.032	0.030	0.023	0.032	0.028	0.034
	Mean	**0.021**	**0.0208**	**0.022**	**0.025**	**0.028**	**0.027**	**0.0342**	**0.033**	**0.034**
T+C	1	0.022	0.023	0.02	0.021	0.025	0.018	0.025	0.024	0.024
	2	0.02	0.022	0.02	0.023	0.024	0.023	0.025	0.023	0.025
	3	0.021	0.02	0.021	0.021	0.024	0.026	0.027	0.025	0.026
	4	0.02	0.019	0.022	0.021	0.019	0.023	0.026	0.025	0.024
	5	0.021	0.021	0.019	0.022	0.021	0.023	0.026	0.024	0.024
	Mean	**0.021**	**0.021**	**0.0204**	**0.022**	**0.0226**	**0.023**	**0.026**	**0.024**	**0.025**
T+C+St	1	0.018	0.019	0.022	0.021	0.018	0.019	0.022	0.023	0.021
	2	0.021	0.022	0.021	0.023	0.024	0.023	0.024	0.024	0.023
	3	0.022	0.021	0.018	0.024	0.023	0.022	0.023	0.024	0.024

	4	0.019	0.018	0.021	0.024	0.024	0.017	0.022	0.022	0.022
	5	0.017	0.018	0.018	0.021	0.021	0.020	0.024	0.022	0.023
	Mean	**0.019**	**0.0196**	**0.0200**	**0.023**	**0.022**	**0.020**	**0.0230**	**0.023**	**0.023**
M+C+St	1	0.053	0.054	0.051	0.055	0.057	0.054	0.061	0.059	0.059
	2	0.052	0.046	0.052	0.056	0.058	0.059	0.056	0.061	0.059
	3	0.052	0.051	0.054	0.053	0.052	0.056	0.058	0.058	0.063
	4	0.051	0.051	0.053	0.054	0.054	0.055	0.062	0.062	0.061
	5	0.051	0.053	0.056	0.055	0.053	0.055	0.059	0.056	0.058
	Mean	**0.052**	**0.051**	**0.0532**	**0.055**	**0.0548**	**0.056**	**0.0592**	**0.059**	**0.060**
T+C+P	1	0.017	0.017	0.016	0.018	0.018	0.017	0.023	0.021	0.023
	2	0.015	0.017	0.016	0.018	0.015	0.017	0.022	0.021	0.021
	3	0.016	0.017	0.014	0.017	0.015	0.015	0.022	0.024	0.023
	4	0.017	0.014	0.015	0.016	0.018	0.016	0.024	0.024	0.021
	5	0.015	0.015	0.016	0.018	0.017	0.016	0.022	0.021	0.022
	Mean	**0.016**	**0.016**	**0.0154**	**0.017**	**0.0166**	**0.016**	**0.0226**	**0.022**	**0.022**

Appendix 2.1 **The Maize Harvest at Wang Jia in 1998** (Harvest Date: 23/10/1998)

Items / Treatment	Fresh cob	Dry grain	Dry yield	Dry stem	Dry stem	DM of stem	Total Biomass
	(kg/30m^2)	(kg/30m^2)	(kg/ha)	(kg/30m^2)	(kg/30m^2)	(kg/ha)	(kg/ha)
T+D	31.20	15.64	5213.52	22.50	1.46	485.52	5699.04
T+C	33.85	16.97	5656.34	28.00	2.08	693.03	6349.36
T+C+St	29.20	14.64	4879.32	20.00	1.23	409.89	5289.21
M+C+St	31.80	15.94	5313.78	24.50	1.69	564.81	5878.59
T+C+P	35.15	17.62	5873.57	28.00	2.00	667.40	6540.96
T+D	24.45	12.26	4085.60	16.50	1.00	333.18	4418.78
T+C	26.00	13.03	4344.60	17.00	1.00	332.60	4677.20
T+C+St	30.35	15.21	5071.49	23.50	1.63	544.47	5615.95
M+C+St	28.35	14.21	4737.29	17.50	0.97	323.23	5060.52
T+C+P	30.15	15.11	5038.07	28.00	2.33	778.08	5816.14
T+D	30.60	15.34	5113.26	22.00	1.42	473.28	5586.54
T+C	32.59	16.34	5445.79	22.00	1.33	444.38	5890.17
T+C+St	31.75	15.92	5305.43	24.00	1.63	542.84	5848.27
M+C+St	30.45	15.26	5088.20	20.50	1.24	412.97	5501.16
T+C+P	35.15	17.62	5873.57	29.50	2.22	740.82	6614.38

Appendix 2.2 Dry Matter of Maize at Wang Jia Experiment in 1998 (A)

Block A: Harvest Date: 23/10/98

Plant number	Treatment	Plant weight	Weight of stem + leaf	Weight of leaf	Weight of cobs	Weight of grain	Weight of stem	Grain Yield
		(g)	(g)	(g)	(g)	(g)	(g)	t/ha
T+D	A1-1	199.709	72.14	47.209	127.569	106.357	24.931	6.45
	A1-2	108.36	42.276	26.334	66.084	54.61	15.942	3.31
	A1-3	188.496	68.173	41.522	120.323	99.846	26.651	6.06
	A1-4	143.042	47.343	30.286	95.699	77.186	17.057	4.68
	A1-5	206.484	78.499	51.045	127.985	106.136	27.454	6.44
	A1-6	181.754	63.047	41.721	118.707	100.69	21.326	6.11
	A1-7	121.3	53.433	33.206	67.867	53.384	20.227	3.24
	A1-8	240.579	83.988	55.792	156.591	105.314	28.196	6.39
	Mean	**173.716**	**63.612**	**40.889**	**110.1**	**87.9**	**22.723**	5.34
T+C	A4-1	226.275	84.46	52.868	141.815	124.829	31.592	7.57
	A4-2	292.099	103.259	69.394	188.84	155.703	33.865	9.45
	A4-3	293.542	116.581	74.257	176.961	142.616	42.324	8.65
	A4-4	218.56	78.322	46.851	140.238	115.186	31.471	6.99
	A4-5	208.306	70.978	43.843	137.328	116.13	27.135	7.05
	A4-6	224.534	80.455	50.133	144.079	119.93	30.322	7.28
	A4-7	286.678	100.182	61.134	186.496	151.862	39.048	9.21
	A4-8	175.084	64.124	39.881	110.96	95.316	24.243	5.78
	Mean	**240.635**	**87.295**	**54.8**	**153.3**	**127.7**	**32.5**	7.75
T+C+St	A5-1	242.423	79.631	51.309	162.792	132.328	28.322	8.03
	A5-2	195.116	65.758	43.037	129.358	106.323	22.721	6.45
	A5-3	255.356	85.554	58.232	169.802	110.413	27.322	6.70
	A5-4	240.399	79.471	52.301	160.928	130.221	27.17	7.90
	A5-5	181.321	62.95	43.739	118.371	99.204	19.211	6.02
	A5-6	168.019	52.971	35.633	115.048	95.544	17.338	5.80

	A5-7	204.16	62.327	42.493	141.833	120.313	19.834	7.30
	A5-8	191.582	57.368	37.886	134.214	110.741	19.482	6.72
	Mean	**209.797**	**68.254**	**45.6**	**141.5**	**113.1**	**22.675**	6.86
M+T+St	A3-1	259.237	94.477	64.198	164.76	136.275	30.279	8.27
	A3-2	318.903	120.921	78.636	197.982	162.5	42.285	9.86
	A3-3	191.452	67.154	43.009	124.298	100.118	24.145	6.07
	A3-4	199.063	72.258	49.004	126.805	104.261	23.254	6.33
	A3-5	203.986	80.432	54.832	123.554	100.322	25.6	6.09
	A3-6	205.752	98.338	65.555	107.414	137.413	32.783	8.34
	A3-7	237.349	82.892	53.066	154.457	126.356	29.826	7.67
	A3-8	195.265	71.648	46.387	123.617	102.651	25.261	6.23
	Mean	**226.376**	**86.015**	**56.8**	**140.4**	**121.2**	**29.2**	7.36
T+C+P	A2-1	289.922	99.65	62.543	190.272	160.17	37.107	9.72
	A2-2	195.229	68.242	46.176	126.987	106.315	22.066	6.45
	A2-3	210.809	79.707	54.628	131.102	106.925	25.079	6.49
	A2-4	305.085	106.927	65.384	198.158	166.179	41.543	10.08
	A2-5	234.38	88.512	60.133	145.868	123.56	28.379	7.50
	A2-6	234.548	80.941	50.222	153.607	127.212	30.719	7.72
	A2-7	278.638	98.462	62.637	180.176	148.942	35.825	9.04
	A2-8	211.569	71.829	44.906	139.74	110.203	26.923	6.69
	Mean	**245.023**	**86.784**	**55.8**	**158.2**	**131.2**	**31.0**	7.96

Appendix 2.3 Dry Matter of Maize at Wang Jia Experiment in 1998

Block B Harvest Date: 23/10/98

Treatment	Sample number	Plant weight (g)	Weight of stem & leaf (g)	Weight of leaf (g)	Weight of cob (g)	Weight of grain (g)	Yield (kg/ha)	Weight of stem (g)
T+D	B1-1	211.12	59.28	40.34	151.84	115.03	**6979**	18.94
	B1-2	134.32	40.08	26.27	94.24	79.00	**4793**	13.81
	B1-3	175.53	59.24	36.70	116.29	97.31	**5903**	22.54
	B1-4	174.91	56.47	38.58	118.44	95.68	**5804**	17.89
	B1-5	206.21	69.00	43.43	137.22	111.77	**6780**	25.57
	B1-6	174.54	56.93	40.27	117.61	98.54	**5978**	16.66
	B1-7	142.16	56.67	35.58	85.49	71.60	**4343**	21.10
	B1-8	133.78	39.46	25.29	94.31	80.95	**4911**	14.17
	Mean	**169.07**	**54.64**	**35.81**	**114.43**	**93.73**	**5686**	**18.83**
T+C	B5-1	196.98	71.93	45.32	125.05	102.97	**6247**	26.61
	B5-2	194.45	63.18	42.82	131.28	109.07	**6617**	20.36
	B5-3	187.28	58.26	39.00	129.02	107.18	**6502**	19.26
	B5-4	274.45	83.67	60.74	190.78	159.30	**9664**	22.93
	B5-5	144.90	48.27	33.41	96.63	80.67	**4894**	14.86
	B5-6	197.36	71.26	47.77	126.10	99.14	**6014**	23.49
	B5-7	195.32	87.72	58.81	107.59	84.62	**5133**	28.91
	B5-8	192.15	73.07	49.11	119.08	97.46	**5913**	23.96
	Mean	**197.86**	**69.67**	**47.12**	**128.19**	**105.05**	**6373**	**22.55**
T+C+St	B3-1	177.11	62.38	42.32	114.73	98.35	**5966**	20.07
	B3-2	138.19	42.66	28.52	95.53	80.55	**4887**	14.14
	B3-3	177.74	70.26	49.27	107.49	89.66	**5439**	20.99
	B3-4	207.61	71.80	45.91	135.81	115.51	**7007**	25.89
	B3-5	209.10	70.54	50.75	138.57	113.91	**6911**	19.79
	B3-6	205.55	70.83	46.10	134.72	111.41	**6759**	24.72

	B3-7	208.36	69.83	46.54	138.54	116.54	**7070**	23.29
	B3-8	240.49	95.54	60.69	144.96	111.85	**6786**	34.85
	Mean	**195.52**	**69.23**	**46.26**	**126.29**	**104.72**	**6353**	**22.97**
M+T+St	B2-1	140.56	52.12	33.35	88.44	73.24	**4443**	18.77
	B2-2	214.77	72.23	48.32	142.54	118.46	**7187**	23.91
	B2-3	153.96	46.75	30.50	107.21	89.33	**5419**	16.26
	B2-4	146.38	55.44	37.83	90.94	75.00	**4550**	17.61
	B2-5	280.49	87.54	58.99	192.95	162.29	**9846**	28.55
	B2-6	165.54	56.21	35.11	109.34	98.09	**5951**	21.10
	B2-7	133.44	41.49	21.48	91.95	77.46	**4699**	20.01
	B2-8	170.47	58.73	38.12	111.74	92.84	**5632**	20.61
	Mean	**175.70**	**58.81**	**37.96**	**116.89**	**98.34**	**5966**	**20.85**
T+C+P	B4-1	366.44	131.19	88.59	235.25	195.42	**11856**	42.60
	B4-2	257.47	79.22	49.62	178.25	148.93	**9035**	29.60
	B4-3	192.08	69.37	40.75	122.71	100.38	**6090**	28.63
	B4-4	187.48	63.89	40.62	123.60	109.15	**6621**	23.26
	B4-5	250.55	82.66	47.53	167.89	137.62	**8349**	35.13
	B4-6	278.80	98.57	61.52	180.23	152.94	**9278**	37.05
	B4-7	259.21	94.82	61.72	164.39	136.83	**8301**	33.10
	B4-8	310.20	117.36	74.25	192.84	159.16	**9656**	43.11
	Mean	**262.78**	**92.13**	**58.07**	**170.64**	**142.55**	**8648**	**34.06**

Appendix 2.4 Dry Matter of Maize at Wang Jia Experiment in 1998

Block C **Harvest** Date: 23/10/98

Treatment	Plant Number	Plant weight	Weight of stem & leaf	Weight of leaf	Weight of cob	Weight of grain	yield	Weight of stem
		(g)	(g)	(g)	(g)	(g)	kg/ha	
T+D	C3-1	196.48	69.13	44.49	127.35	107.76	**6538**	24.64
	C3-2	222.40	76.42	54.31	145.98	112.22	**6808**	22.11
	C3-3	187.22	68.21	43.67	119.01	97.45	**5912**	24.55
	C3-4	182.19	72.04	46.25	110.15	92.15	**5590**	25.79
	C3-5	149.06	58.57	38.76	90.50	74.93	**4546**	19.81
	C3-6	170.85	59.48	37.11	111.37	94.63	**5741**	22.36
	C3-7	201.04	76.43	48.92	124.61	106.26	**6447**	27.51
	C3-8	136.93	50.40	33.79	86.54	69.47	**4214**	16.61
	Mean	**180.77**	**66.33**	**43.41**	**114.44**	**94.36**	5724	**22.92**
T+C	C5-1	203.40	64.87	43.59	138.53	117.61	**7135**	21.28
	C5-2	280.55	89.04	62.90	191.51	161.47	**9796**	26.14
	C5-3	303.34	93.73	58.38	209.61	177.73	**10782**	35.35
	C5-4	218.00	71.80	47.43	146.20	120.86	**7332**	24.37
	C5-5	189.63	64.55	42.44	125.07	101.92	**6183**	22.11
	C5-6	224.73	71.51	46.21	153.22	126.29	**7661**	25.30
	C5-7	245.74	76.88	50.24	168.86	141.46	**8582**	26.64
	C5-8	183.82	59.63	38.43	124.19	105.09	**6376**	21.20
	Mean	**231.15**	**74.00**	**48.70**	**157.15**	**131.55**	7981	**25.30**
T+C+St	C2-1	125.80	45.40	31.09	80.40	67.41	**4090**	14.30
	C2-2	230.11	79.25	51.35	150.86	123.03	**7464**	27.89
	C2-3	184.87	61.78	39.38	123.09	102.15	**6197**	22.40
	C2-4	215.38	80.48	51.57	134.89	110.56	**6707**	28.91
	C2-5	238.50	78.28	52.68	160.23	135.22	**8204**	25.60
	C2-6	185.57	64.40	32.75	121.17	103.95	**6306**	31.65
	C2-7	139.18	58.76	38.24	80.42	66.75	**4050**	20.52

	C2-8	189.07	59.74	40.05	129.34	109.73	**6657**	19.69
	Mean	**188.56**	**66.01**	**47.14**	**122.55**	**102.35**	**6209**	**18.87**
M+C+St	C1-1	175.32	61.69	38.55	113.63	95.18	**5774**	23.15
	C1-2	177.63	66.01	43.03	111.61	91.93	**5577**	22.98
	C1-3	222.86	75.37	52.71	147.49	118.45	**7186**	22.66
	C1-4	223.53	79.78	52.25	143.75	121.46	**7368**	27.53
	C1-5	129.79	46.93	29.35	82.86	68.77	**4172**	17.58
	C1-6	215.01	76.00	50.80	139.00	114.00	**6916**	25.20
	C1-7	220.13	72.68	49.35	147.45	122.29	**7419**	23.33
	C1-8	250.67	77.78	51.27	172.90	139.75	**8478**	26.50
	Mean	**201.87**	**69.53**	**45.91**	**132.34**	**108.98**	**6611**	**23.62**
T+C+P	C4-1	177.21	62.01	41.71	115.19	96.95	**5882**	20.30
	C4-2	187.92	52.43	32.81	135.49	116.48	**7067**	19.62
	C4-3	315.39	103.92	74.96	211.47	177.32	**10757**	28.96
	C4-4	289.62	106.25	67.83	183.37	150.14	**9108**	38.42
	C4-5	202.66	70.60	45.87	132.07	110.34	**6694**	24.73
	C4-6	262.05	87.46	56.47	174.59	141.48	**8583**	31.00
	C4-7	263.46	86.10	58.48	177.36	153.80	**9331**	27.62
	C4-8	321.02	102.17	67.44	218.86	181.81	**11030**	34.73
	Mean	**252.42**	**83.87**	**55.70**	**168.55**	**141.04**	**8556**	**28.17**

Appendix 2.5 Green Leaf Area Index (GLAI) Data at Wang Jia in 1998 and 1999

Green Leaf Area Index (GLAI) Data at Wang Jia in 1998

Treatment	Block	Measurement Date						
		07/07/98	22/07/98	05/08/98	19/08/98	03/09/98	17/09/98	29/09/98
T+D	A	0.252	1.142	2.00	2.859	2.91	2.57	1.71
	B	0.202	0.751	1.62	2.492	2.49	2.19	1.43
	C	0.247	1.252	2.08	2.903	3.08	2.32	1.73
T+C	A	0.318	1.130	2.05	2.980	3.08	2.82	1.96
	B	0.198	0.654	1.45	2.248	2.50	2.23	1.67
	C	0.231	1.571	2.41	3.245	3.21	2.90	1.80
T+C+St	A	0.207	0.954	1.68	2.414	2.49	2.46	1.98
	B	0.293	1.313	2.23	3.149	3.11	2.55	1.31
	C	0.202	0.919	1.67	2.413	2.48	2.32	1.77
M+C+St	A	0.233	0.974	2.09	3.214	3.04	2.32	1.44
	B	0.181	0.699	1.63	2.557	2.27	2.22	1.45
	C	0.332	0.933	1.65	2.376	2.76	2.50	1.27
T+C+P	A	0.546	1.937	2.80	3.654	3.55	3.13	1.82
	B	0.319	1.334	2.09	2.843	3.03	2.88	2.19
	C	0.402	1.298	2.17	3.043	3.00	2.80	2.12

Green Leaf Area Index (GLAI) Data at Wang Jia in 1999

Treatment	Block	Measurement Date						
		30/06/99	14/07/99	29/07/99	13/08/99	28/08/99	13/09/99	28/09/99
T+D	A	0.323	0.89	1.32	2.25	2.23	2.31	0.95
	B	0.292	0.81	0.96	1.73	1.63	1.48	0.32
	C	0.314	0.88	0.91	1.68	1.62	1.36	0.52

T+C	A	0.370	1.20	1.45	2.37	2.21	2.13	0.84
	B	0.322	0.74	1.15	1.95	1.80	1.52	0.21
	C	0.265	1.40	1.10	1.96	1.91	1.65	0.56
T+C+St	A	0.306	1.15	1.25	1.90	1.91	1.91	0.76
	B	0.445	1.27	1.62	2.59	2.65	2.46	0.64
	C	0.354	1.21	1.25	2.07	2.21	1.86	0.64
M+C+St	A	0.334	0.90	1.45	2.49	2.41	2.12	0.94
	B	0.266	0.79	0.97	1.82	1.75	1.56	0.59
	C	0.266	1.10	1.28	2.02	2.01	1.73	0.85
T+C+P	A	0.958	1.69	3.19	3.48	3.74	2.13	0.84
	B	0.735	1.27	2.25	2.81	2.80	2.25	0.78
	C	0.903	1.49	2.46	3.16	2.60	2.65	0.84

Appendix 2.6 Green Leaf Number Data at Wang Jia in 1998 and 1999

Green Leaf Number Data at Wang Jia in 1998

Treatment	Block	Measurement Date						
		07/07/98	22/07/98	05/08/98	19/08/98	03/09/98	17/09/98	29/09/98
T+D	A	3.3	5.8	9.3	10.9	11.0	9.8	8.3
	B	3.3	5.0	8.9	11.3	11.3	10.4	7.8
	C	3.3	6.3	8.0	11.3	11.0	9.5	7.6
T+C	A	3.6	5.5	9.9	11.3	11.0	10.8	8.5
	B	3.3	4.4	8.9	10.3	10.1	9.3	6.9
	C	3.6	6.4	9.3	11.4	10.9	9.9	8.3
T+C+St	A	3.0	5.0	9.5	10.6	10.6	10.0	8.8
	B	3.6	5.9	10.4	11.0	10.9	9.4	6.9
	C	3.1	5.3	9.5	11.5	10.6	10.0	8.4
M+C+St	A	2.9	5.0	9.3	11.6	11.1	8.6	6.8
	B	2.6	4.3	8.5	11.5	10.6	10.0	8.4
	C	2.5	5.1	8.9	11.1	10.5	9.9	7.0
T+C+P	A	5.1	6.9	12.5	11.5	11.4	10.4	8.0
	B	4.0	6.6	10.0	11.3	11.5	10.8	9.1
	C	4.3	6.8	11.5	11.6	11.5	11.0	9.6

Green Leaf Number Data at Wang Jia in 1999

Treatment	Block	Measurement Date						
		30/06/99	14/07/99	29/07/99	13/08/99	28/08/99	13/09/99	28/09/99
T+D	A	3.6	5.1	7.4	12.0	11.4	10.4	2.4
	B	4.0	5.5	6.9	10.4	10.6	9.3	1.5
	C	4.0	5.5	6.4	11.3	10.8	8.5	3.3

T+C	A	4.5	5.5	8.4	12.5	10.9	10.1	3.3
	B	4.0	5.0	8.0	11.1	9.8	7.8	1.3
	C	4.1	6.0	7.6	11.0	9.6	8.6	2.5
T+C+St	A	4.4	5.6	8.3	9.4	9.9	9.3	3.1
	B	4.5	5.8	8.0	11.4	11.4	10.1	1.6
	C	4.4	6.1	7.4	11.1	11.5	9.4	2.8
M+C+St	A	3.9	4.6	8.0	11.1	11.1	9.3	3.8
	B	3.5	4.3	7.6	10.9	10.5	9.4	3.0
	C	4.3	5.8	7.9	11.0	10.6	8.3	3.8
T+C+P	A	6.4	6.6	11.3	12.6	11.6	6.6	2.1
	B	5.5	6.8	9.5	11.9	11.4	8.4	2.5
	C	6.3	7.3	10.3	12.5	12.0	9.8	2.6

Appendix 2.7 Plant Height Data at Wang Jia in 1998 and 1999

Plant Height (cm) Data at Wang Jia in 1998

Treatment	Block	Measurement Date						
		07/07/98	22/07/98	05/08/98	19/08/98	03/09/98	17/09/98	29/09/98
T+D	A	79.9	121.7	147.5	199.0	194.8	196.9	196.9
	B	62.3	81.9	130.3	178.7	178.0	176.0	176.0
	C	77.3	123.9	149.1	174.3	200.1	198.6	198.6
T+C	A	74.0	122.7	151.8	180.9	204.9	205.6	205.6
	B	59.9	98.5	142.6	172.8	185.3	162.3	162.3
	C	88.8	135.2	154.0	186.6	200.3	197.6	197.6
T+C+St	A	67.4	101.3	126.7	152.0	181.4	182.8	182.8
	B	60.0	120.6	150.1	179.6	199.9	206.5	206.5
	C	78.4	106.8	142.9	179.0	187.6	184.1	184.1
M+C+St	A	70.9	113.3	154.4	195.6	200.6	201.8	201.8
	B	61.3	91.0	136.0	181.0	174.7	180.4	180.4
	C	71.8	106.8	139.0	171.1	197.4	194.9	194.9
T+C+P	A	100.8	148.3	172.0	195.6	224.5	224.0	224.0
	B	73.2	106.5	160.4	188.5	202.3	199.1	199.1
	C	83.0	125.3	155.0	184.6	207.6	208.7	208.7

Plant Height Data at Wang Jia in 1999

Treatment	Block	Measurement Date						
		30/06/99	14/07/99	29/07/99	13/08/99	28/08/99	13/09/99	28/09/99
T+D	A	70.3	84.4	104.2	206.0	204.9	202.8	202.8
	B	61.9	70.1	84.7	175.6	172.4	176.1	176.1

	C	61.1	71.0	83.6	179.5	178.8	177.6	177.6
T+C	A	72.9	84.1	102.9	200.4	198.8	201.8	201.8
	B	58.8	67.6	90.0	179.1	177.7	179.1	179.1
	C	61.0	74.0	95.8	193.3	193.1	189.8	189.8
T+C+St	A	68.4	81.3	102.6	186.9	192.3	194.1	194.1
	B	76.3	100.3	122.8	209.9	213.3	216.1	216.1
	C	67.6	72.9	96.6	192.8	183.3	189.3	189.3
M+C+St	A	74.6	84.9	111.0	206.1	204.4	207.5	207.5
	B	64.4	70.6	87.5	172.4	176.0	184.8	184.8
	C	65.1	77.4	101.3	198.8	196.4	198.4	198.4
T+C+P	A	106.8	135.4	170.3	220.3	219.0	218.5	218.5
	B	92.0	112.6	145.3	210.8	215.3	216.1	216.1
	C	94.3	113.5	144.8	213.1	211.4	213.1	213.1

Appendix 3.1 Soil Temperature Measurement at Wang Jia in 1999 (n = 5) (^{o}C)

30/06/98	0730-0830					1330-1430					1730-1830				
	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm
T+D	14.7	16.6	17.9	19	19.7	23.6	22.6	20.4	19.9	19.9	19.6	22.1	22.5	21.7	21.1
T+C	15.7	16.4	17.4	18.3	19	29.5	25.5	21.7	20.6	19.9	18.1	20.5	21.8	21.5	21.1
T+C+St	15.8	16.4	17.3	18.1	18.7	28.5	25.3	21.6	20.2	20.0	17.6	20.1	21.4	21.3	20.8
M+C+St	15.4	16.2	17.4	18.5	19.1	29.3	25.9	21.4	20.3	19.7	18.5	21.0	21.7	21.2	20.8
T+C+P	15.5	17.8	19.1	19.8	20.4	34.9	29.1	25.0	23.5	21.7	23.5	25.5	25.2	24.1	23.2
14/07/98	0730-0830					1330-1430					1730-1830				
	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm
T+D	18.8	19.2	19.4	20.0	20.3	24.9	24.0	22.5	21.6	21.2	23.1	23.4	22.8	22.0	21.6
T+C	18.8	19.2	19.5	19.9	20.5	24.7	24.4	22.9	22.1	21.0	23.2	23.5	23.0	22.2	21.5
T+C+St	19.0	19.3	19.7	20.1	20.5	24.7	23.8	22.5	21.3	20.9	23.3	23.3	22.9	22.1	21.5
M+C+St	19.0	19.2	19.5	20.0	20.3	25.6	24.0	21.6	21.4	20.9	23.5	23.3	22.6	22.0	21.5
T+C+P	19.1	19.4	19.8	20.2	20.4	26.1	25.0	23.7	22.2	21.7	24.3	24.2	23.7	22.7	21.9
30/07/99	0730-0830					1330-1430					1730-1830				
	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm
T+D	19.0	19.4	19.8	20.2	20.6	27.7	24.6	23.1	21.6	20.9	25.1	24.5	23.4	22.5	21.7
T+C	18.9	19.3	19.8	20.3	20.6	25.9	23.3	21.9	21.3	20.9	24.1	24.5	23.3	22.3	21.8
T+C+St	19.2	19.7	20.0	20.4	20.8	25.5	23.8	22.4	21.5	20.9	23.7	23.9	22.9	22.2	21.7
M+C+St	19.0	19.4	19.8	20.1	20.5	25.2	23.3	22.3	21.4	20.9	23.8	23.7	22.9	22.2	21.6
T+C+P	19.0	19.3	19.9	20.2	20.3	26.9	24.7	23.8	22.2	21.1	25.6	25.0	23.9	22.5	21.8
15/08/99	0730-0830					1330-1430					1730-1830				
	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm
T+D	18.8	19.3	19.8	20.2	20.5	23.6	23.1	21.9	21.3	21.1	22.2	22.7	22.3	21.8	21.4
T+C	18.3	19.0	19.4	19.7	20.4	23.1	22.3	21.5	20.9	20.6	22.3	22.8	22.2	22.0	21.5
T+C+St	18.2	19.2	19.5	19.9	20.5	22.7	21.9	21.2	20.8	20.5	22.0	22.4	22.2	21.8	21.4
M+C+St	18.3	19.1	19.5	20.0	20.5	22.7	21.8	21.1	20.7	20.4	21.8	22.3	21.9	21.5	21.1
T+C+P	18.9	19.4	19.8	20.0	20.3	23.2	22.1	21.3	20.7	20.4	22.2	22.4	22.1	21.7	21.2
30/08/99	0730-0830					1330-1430					1730-1830				
	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm

T+D	17.9	18.3	18.7	19.0	19.4	21.0	19.7	19.2	19.1	19.0	20.4	21.0	20.4	19.6	19.4
T+C	17.7	18.1	18.4	18.9	19.2	20.3	19.7	19.1	18.9	18.8	20.1	20.9	20.4	19.8	19.3
T+C+St	17.9	18.3	18.7	19.1	19.2	20.6	19.7	19.1	18.9	18.9	19.8	20.6	20.1	19.7	19.3
M+C+St	17.6	18.0	18.5	18.8	19.1	20.3	19.7	19.1	19.0	18.9	19.5	20.4	20.0	19.5	19.2
T+C+P	18.0	18.3	18.7	19.0	19.3	20.9	19.7	19.1	18.9	18.8	20.5	20.9	20.1	19.5	19.2
14/09/99	0730-0830					1330-1430					1730-1830				
	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm
T+D	17.1	18.1	18.9	19.3	19.8	24.2	22.5	21.3	20.6	19.8	20.4	21.3	21.7	21.2	20.5
T+C	16.8	17.4	18.2	18.9	19.3	27.1	23.1	21.2	20.3	19.7	19.6	21.3	21.8	21.5	20.5
T+C+St	17.4	18.1	18.9	19.5	19.9	26.3	23.0	21.8	20.7	19.9	20.0	21.1	21.4	21.0	20.6
M+C+St	17.5	18.1	18.7	19.2	19.6	27.0	24.0	21.9	20.9	20.0	19.4	21.5	21.5	21.3	20.7
T+C+P	17.8	18.5	19.1	19.5	19.9	28.7	23.5	21.5	20.9	20.1	21.0	21.5	21.7	21.2	20.5
28/09/99	0730-0830					1330-1430					1730-1830				
	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm	0cm	5cm	10cm	15cm	20cm
T+D	15.1	16.3	17.7	17.9	18.3	27.9	22.4	20.6	19.3	19.07	18.7	20.6	20.9	20.5	20.1
T+C	16.5	17.4	18.1	18.6	19.0	23.7	21.5	19.3	17.3	16.93	17.7	19.3	19.9	19.8	19.5
T+C+St	16.9	17.7	18.1	18.6	19.2	23.0	21.3	19.7	17.5	17.27	18.2	19.4	20.2	19.9	19.4
M+C+St	16.6	17.5	18.1	18.6	19.1	25.3	22.0	20.13	18.5	18.27	17.6	19.2	20.0	19.8	19.5
T+C+P	16.1	17.7	18.3	18.7	19.1	26.7	21.2	19.17	18.2	18.73	18.1	19.7	19.9	19.7	19.3

Appendix 3.2 Soil Moisture (% by weight)Measurement Data at Wang Jia in 1999

(n = 5)

Measurement date		28/06/99			13/07/99			31/07/99			16/08/99		
Treatment	Block	Soil Depth (cm)			Soil Depth (cm)			Soil Depth (cm)			Soil Depth (cm)		
		0-5	5-10	10-15	0-5	5-10	10-15	0-5	5-10	10-15	0-5	5-10	10-15
T+D	a	15.64	17.64	18.91	16.36	17.37	18.18	18.87	19.38	19.78	22.94	20.87	19.87
	b	18.56	18.22	20.01	17.84	18.45	18.68	19.47	18.89	18.80	21.01	20.57	21.32
	c	20.16	19.26	19.08	15.73	16.88	16.34	19.01	18.48	18.22	19.95	19.43	18.91
	Mean	**18.12**	**18.38**	**19.33**	**16.64**	**17.57**	**17.74**	**19.12**	**18.92**	**18.93**	**21.30**	**20.29**	**20.03**
T+C	a	18.74	19.64	19.13	17.64	19.18	19.41	22.53	20.42	20.40	23.01	23.20	20.40
	b	17.32	19.94	19.01	16.96	17.89	17.47	19.52	18.24	19.65	21.01	20.57	21.32
	c	19.24	20.34	19.91	17.37	17.44	16.52	18.89	18.23	17.75	20.17	19.65	19.31
	Mean	**18.43**	**19.97**	**19.35**	**17.32**	**18.17**	**17.80**	**20.31**	**18.97**	**19.27**	**21.40**	**21.14**	**20.34**
T+C+St	a	19.57	19.11	19.17	19.05	18.94	19.17	21.26	20.00	20.14	23.47	21.52	21.56
	b	19.40	19.33	20.01	19.41	19.95	19.63	20.42	20.74	20.19	22.82	22.20	23.33
	c	20.40	20.24	19.30	17.10	17.44	16.59	18.83	18.26	18.73	21.04	19.95	19.87
	Mean	**19.79**	**19.56**	**19.49**	**18.52**	**18.78**	**18.46**	**20.17**	**19.67**	**19.69**	**22.44**	**21.22**	**21.59**
M+C+St	a	19.16	19.71	18.83	18.85	16.81	17.59	21.64	21.83	21.67	22.44	22.02	22.22
	b	19.40	19.33	20.01	18.54	17.88	17.12	20.79	21.54	20.15	22.18	21.90	22.04
	c	19.74	19.73	19.85	17.79	17.61	17.42	21.11	19.87	21.60	21.29	23.39	22.74
	Mean	**19.43**	**19.59**	**19.56**	**18.39**	**17.43**	**17.37**	**21.18**	**21.08**	**21.14**	**21.97**	**22.43**	**22.34**
T+C+P	a	20.18	20.07	20.20	20.19	19.75	19.89	17.72	18.58	18.96	18.41	18.43	18.95
	b	22.29	23.10	22.56	18.94	18.50	19.59	19.34	19.38	19.26	20.75	19.77	20.62
	c	22.63	22.88	21.45	17.10	17.44	16.59	17.58	17.81	17.56	18.03	18.98	19.63
	Mean	**21.70**	**22.02**	**21.40**	**18.75**	**18.56**	**18.69**	**18.21**	**18.59**	**18.60**	**19.06**	**19.06**	**19.73**
		29/08			12/09			27/09					
		0-5	5-10	10-15	0-5	5-10	10-15	0-5	5-10	10-15			
T+D	a	21.36	20.54	19.27	17.03	18.24	17.26	18.80	19.64	18.63			
	b	21.21	19.60	18.99	17.86	16.70	16.46	19.43	18.75	18.35			

	c	19.98	22.50	18.96	15.52	15.99	16.34	16.26	18.30	20.31			
	Mean	**20.85**	**20.88**	**19.07**	**16.80**	**16.98**	**16.69**	**18.16**	**18.89**	**19.09**			
T+C	a	22.11	21.71	20.95	19.58	20.91	20.21	17.68	19.71	19.19			
	b	19.65	19.83	19.90	14.02	16.87	16.88	15.72	18.75	18.26			
	c	17.84	17.97	17.93	14.69	17.45	16.85	16.68	18.69	17.92			
	Mean	**19.87**	**19.84**	**19.59**	**16.10**	**18.41**	**17.98**	**16.69**	**19.05**	**18.46**			
T+C+St	a	21.91	21.34	20.71	20.31	18.72	19.21	20.14	20.11	19.49			
	b	22.17	21.14	20.89	20.27	19.23	18.69	20.38	20.33	20.12			
	c	20.72	18.76	18.62	15.24	18.21	16.05	13.85	17.36	16.91			
	Mean	**21.60**	**20.41**	**20.07**	**18.61**	**18.72**	**17.98**	**18.12**	**19.26**	**18.84**			
M+C+St	a	21.98	21.29	20.68	19.13	19.20	19.97	19.81	19.82	20.58			
	b	21.98	21.00	21.00	16.98	19.62	17.53	17.70	18.77	19.04			
	c	20.42	19.80	19.45	16.16	17.14	17.41	19.11	18.83	19.46			
	Mean	**21.46**	**20.69**	**20.38**	**17.43**	**18.65**	**18.30**	**18.87**	**19.14**	**19.69**			
T+C+P	a	19.45	21.32	20.32	17.00	18.32	18.59	19.65	19.31	19.32			
	b	19.98	20.65	20.03	17.78	17.72	18.72	16.73	18.26	18.48			
	c	17.83	17.53	19.25	14.49	16.67	15.25	18.62	18.82	18.14			
	Mean	**19.09**	**19.83**	**19.87**	**16.42**	**17.57**	**17.52**	**18.33**	**18.80**	**18.65**			

Appendix 3.3 Soil Penetrometer Reading (kg cm^{-2}) at Wang Jia in 1999

Treatment	No.	25/06/99			02/08/99			28/09/99		
		Block A	Block B	Block C	Block A	Block B	Block C	Block A	Block B	Block C
T+D	1	0.016	0.018	0.018	0.02	0.019	0.023	0.025	0.023	0.033
	2	0.018	0.019	0.016	0.018	0.021	0.024	0.023	0.025	0.032
	3	0.017	0.02	0.017	0.019	0.018	0.023	0.027	0.024	0.034
	4	0.018	0.017	0.014	0.017	0.02	0.021	0.024	0.021	0.028
	5	0.019	0.014	0.017	0.019	0.021	0.022	0.026	0.02	0.035
	Mean	**0.0176**	**0.0176**	**0.0164**	**0.0186**	**0.0198**	**0.0226**	**0.025**	**0.0226**	**0.0324**
T+C	1	0.019	0.019	0.017	0.021	0.023	0.021	0.023	0.026	0.022
	2	0.018	0.016	0.016	0.024	0.021	0.021	0.035	0.028	0.023
	3	0.017	0.017	0.017	0.023	0.02	0.023	0.026	0.024	0.024
	4	0.016	0.018	0.016	0.024	0.023	0.024	0.028	0.026	0.028
	5	0.02	0.016	0.019	0.024	0.024	0.019	0.027	0.027	0.021
	Mean	**0.018**	**0.0172**	**0.017**	**0.0232**	**0.0222**	**0.0216**	**0.028**	**0.026**	**0.024**
T+C+St	1	0.016	0.014	0.012	0.018	0.019	0.017	0.019	0.023	0.021
	2	0.015	0.018	0.014	0.017	0.018	0.012	0.017	0.021	0.019
	3	0.014	0.016	0.015	0.018	0.013	0.016	0.02	0.023	0.018
	4	0.013	0.017	0.013	0.016	0.02	0.013	0.018	0.019	0.02
	5	0.012	0.014	0.018	0.014	0.014	0.014	0.021	0.018	0.017
	Mean	**0.014**	**0.0158**	**0.0144**	**0.0166**	**0.0168**	**0.0144**	**0.019**	**0.0208**	**0.019**
M+C+St	1	0.048	0.058	0.058	0.053	0.065	0.061	0.066	0.075	0.065
	2	0.056	0.057	0.056	0.052	0.064	0.062	0.068	0.074	0.064
	3	0.061	0.061	0.061	0.062	0.067	0.058	0.064	0.076	0.063
	4	0.064	0.068	0.062	0.054	0.071	0.057	0.063	0.078	0.076
	5	0.056	0.064	0.059	0.064	0.072	0.062	0.058	0.081	0.062
	Mean	**0.057**	**0.0616**	**0.0592**	**0.057**	**0.0678**	**0.06**	**0.0638**	**0.0768**	**0.066**
T+C+P	1	0.022	0.021	0.02	0.021	0.022	0.023	0.017	0.017	0.018
	2	0.018	0.023	0.024	0.018	0.024	0.021	0.015	0.021	0.021

	3	0.021	0.018	0.023	0.019	0.018	0.02	0.018	0.02	0.019
	4	0.023	0.019	0.018	0.02	0.016	0.021	0.018	0.017	0.022
	5	0.019	0.021	0.019	0.018	0.019	0.019	0.019	0.018	0.023
	Mean	**0.0206**	**0.0204**	**0.0208**	**0.0192**	**0.0198**	**0.0208**	**0.0174**	**0.0186**	**0.0206**

Appendix 3.4 Soil Bulk Density Measurements (g cm^{-3}) at Wang Jia in 1999

Block	Treatment	Depth (cm)	Measurement Date		
			22/06/99	02/08/99	25/09/99
			Soil Bulk Density (g cm^{-3})	Soil Bulk Density (g cm^{-3})	Soil Bulk Density (g cm^{-3})
A	T+D	0-10	1.319	1.232	1.269
		10-20	1.119	1.222	1.259
	T+C	0-10	1.272	1.255	1.255
		10-20	1.185	1.393	1.353
	T+C+St	0-10	1.189	1.187	1.287
		10-20	1.221	1.296	1.296
	M+C+St	0-10	1.224	1.278	1.287
		10-20	1.188	1.231	1.296
	T+C+P	0-10	1.168	1.211	1.211
		10-20	1.137	1.160	1.260
B	T+D	0-10	1.285	1.354	1.354
		10-20	1.278	1.287	1.287
	T+C	0-10	1.187	1.297	1.297
		10-20	1.359	1.289	1.289
	T+C+St	0-10	1.264	1.304	1.304
		10-20	1.216	1.247	1.263
	M+C+St	0-10	1.233	1.268	1.268
		10-20	1.208	1.307	1.317
	T+C+P	0-10	1.179	1.189	1.189

		10-20	1.318	1.308	1.308
C	T+D	0-10	1.209	1.353	1.353
		10-20	1.155	1.365	1.365
	T+C	0-10	1.217	1.322	1.322
		10-20	1.259	1.327	1.327
	T+C+St	0-10	1.259	1.249	1.394
		10-20	1.266	1.285	1.411
	M+C+St	0-10	1.222	1.200	1.200
		10-20	1.229	1.240	1.240
	T+C+P	0-10	1.226	1.394	1.249
		10-20	1.228	1.231	1.285

Appendix 3.5 Maize harvest at Wang Jia in the 1999 cropping season

Harvest Date: 7/10/1999

Items / Treatment	Fresh cob	Dry grain	Dry yield	Fresh stem	Dry stem	Dry stem	DM of stem	Total Biomass
	($kg/30m^2$)	($kg/30m^2$)	(kg/ha)	($kg/30m^2$)	($kg/30m^2$)	($kg/30m^2$)	(kg/ha)	kg/ha
T+D	42.55	16.03	5343.33	510.80	184.30	184.30	61433.33	66776.67
T+C	45.94	19.31	6436.67	554.40	212.10	212.10	70700.00	77136.67
T+C+St	47.43	20.09	6696.67	579.40	225.50	225.50	75166.67	81863.33
M+C+St	47.63	19.75	6583.33	581.60	222.00	222.00	74000.00	80583.33
T+C+P	57.09	24.95	8316.67	757.00	284.00	284.00	94666.67	102983.33
T+D	39.44	15.72	5240.00	467.50	171.30	171.30	57100.00	62340.00
T+C	42.50	18.33	6110.00	493.80	191.20	191.20	63733.33	69843.33
T+C+St	48.07	19.86	6620.00	608.70	218.00	218.00	72666.67	79286.67
M+C+St	49.50	19.64	6546.67	637.70	217.00	217.00	72333.33	78880.00
T+C+P	53.73	24.17	8056.67	685.10	266.30	266.30	88766.67	96823.33
T+D	55.16	19.00	6333.33	718.30	276.80	276.80	92266.67	98600.00
T+C	49.45	21.60	7200.00	573.90	227.20	227.20	75733.33	82933.33
T+C+St	45.61	20.78	6926.67	611.20	212.60	212.60	70866.67	77793.33
M+C+St	57.46	24.78	8260.00	703.70	270.90	270.90	90300.00	98560.00
T+C+P	47.37	25.33	8443.33	548.00	217.90	217.90	72633.33	81076.67

Appendix 4.1 Fresh plant measurements for Wang Jia non-irrigated experiment in 1999

Harvest Date: 15/10/99

Treatment	Block	Plant Height	Stem Girth	Leaf number	Plant weight	Weight of stem + leaves	Weight of leaves	Weight of cobs	Cob length	Cob girth	Grain number per 2 rows	Rows
		(cm)	(cm)		(g)	(g)	(g)	(g)	(cm)	(cm)	(grain)	(row)
T+D	A	191.2	5.6	10.9	415.974	92.221	72.065	251.688	16.9	16.7	31.9	13.8
	B	168.1	5.0	10.3	389.988	62.763	104.825	222.400	17.4	16.2	27.8	11.8
	C	172.3	5.3	10.5	347.350	55.563	64.675	227.113	16.8	16.5	29.4	12.8
Mean		**177.2**	**5.3**	**10.5**	**384.437**	**70.182**	**80.522**	**233.733**	**17.0**	**16.5**	**29.7**	**12.8**
T+C	A	194.6	5.6	10.6	440.750	98.275	78.050	264.425	18.4	16.7	31.5	12.8
	B	170.8	5.5	9.6	313.063	51.963	49.850	211.250	17.5	16.0	29.0	12.3
	C	187.0	5.6	9.5	367.475	68.775	69.125	229.575	17.4	16.5	29.6	13.3
Mean		**184.1**	**5.6**	**9.9**	**373.763**	**73.004**	**65.675**	**235.083**	**17.8**	**16.4**	**30.0**	**12.8**
T+C+St	A	184.4	5.5	9.9	389.400	85.963	68.050	235.388	17.5	16.5	29.6	13.8
	B	201.9	6.1	10.1	454.811	113.298	88.738	252.775	18.3	17.0	31.2	13.5
	C	178.6	5.3	8.6	365.938	75.375	67.588	222.975	17.1	16.0	27.3	13.1
Mean		**188.3**	**5.6**	**9.5**	**403.383**	**91.545**	**74.792**	**237.046**	**17.6**	**16.5**	**29.4**	**13.5**
M+C+St	A	197.8	6.0	10.1	430.863	94.625	77.388	258.850	18.4	16.9	32.5	12.8
	B	171.3	5.4	9.6	397.175	126.475	61.763	208.938	16.4	16.5	25.6	12.3
	C	192.3	5.3	10.0	356.338	79.875	65.850	210.613	17.4	15.8	29.1	12.0
Mean		**187.1**	**5.6**	**9.9**	**394.792**	**100.325**	**68.333**	**226.133**	**17.4**	**16.4**	**29.1**	**12.3**
T+C+P	A	202.8	6.7	11.3	516.138	97.600	107.250	311.288	19.8	17.2	39.3	14.5
	B	186.4	6.2	10.3	528.775	129.163	96.788	302.825	20.1	17.6	37.5	13.8
	C	188.2	6.9	11.1	533.975	120.375	99.575	314.025	19.1	17.0	35.1	13.5
Mean		**192.5**	**6.6**	**10.9**	**526.296**	**115.713**	**101.204**	**309.379**	**19.7**	**17.3**	**37.3**	**13.9**

Appendix 4.2 Harvest results for Wang Jia non-irrigated experiment in 1999

Harvest date: 15/10/1999

Items / Treatment	Fresh cob ($kg/30m^2$)	Dry grain ($kg/30m^2$)	Dry yield (kg/ha)	Dry stem ($kg/30m^2$)	DM of stem (kg/ha)	Dry leaves ($kg/30m^2$)	Dry leaves (kg/ha)	Total Biomass (kg/ha)
T+D	45.81	20.24	6746	4.37	1456	8.94	2979	11181
T+C	48.13	24.02	8008	4.82	1608	9.76	3252	12867
T+C+St	42.84	25.64	8548	5.24	1747	10.16	3385	13681
M+T+St	47.11	24.77	8257	5.48	1826	5.48	1826	11909
T+C+P	56.65	30.63	10210	7.77	2590	13.30	4435	17235
T+D	38.03	15.73	5243	4.50	1498	8.94	2979	9720
T+C	38.45	18.33	6109	4.33	1444	8.14	2712	10265
T+C+St	46.01	19.86	6619	5.19	1729	9.94	3312	11660
M+T+St	40.48	19.64	6546	5.01	1668	10.12	3373	11587
T+C+P	55.11	24.17	8057	6.83	2275	9.94	3312	13644
T+D	41.33	19.44	6479	5.22	1741	9.43	3143	11363
T+C	41.78	21.60	7201	5.33	1778	9.78	3258	12237
T+C+St	40.58	19.00	6333	5.28	1759	9.85	3282	11375
M+T+St	48.33	25.33	8445	6.24	2081	12.14	4046	14572
T+C+P	57.15	25.77	8590	7.47	2490	13.56	4520	15600

Appendix 5.1 Soil analyses results for Wang Jia experiment from 1997 to 1999

Block		SOM %	pH	Total N (%)	Total P (%)	Total K (%)	Mean.N (ppm)	Mean P (ppm)	Mean K (ppm)
Soil Sampling date: 04/08/1997									
A	T+D	0.92	5.5	0.05	0.072	3.5	51.0	5.0	79
	T+C	0.81	5.8	0.044	0.06	3.0	43.0	4.3	98
	M+C+St	0.94	5.7	0.051	0.056	3.3	53.0	4.0	112
	T+C+St	0.83	5.6	0.045	0.036	3.1	71.0	4.0	88
	T+C+P	0.88	5.7	0.048	0.062	3.5	58.0	5.3	48
B	T+D	0.57	5	0.031	0.038	3.3	35.0	5.0	57
	T+C	0.52	5.7	0.028	0.027	3.8	40.0	3.9	98
	M+C+St	0.77	5.7	0.042	0.029	3.9	46.0	4.0	111
	T+C+St	0.88	5.6	0.048	0.058	4.0	45.0	5.0	70
	T+C+P	0.85	5.2	0.046	0.032	4.0	47.0	4.4	86
C	T+D	0.59	5	0.032	0.019	4.4	37.0	4.0	87
	T+C	0.66	5.5	0.036	0.043	3.6	39.0	5.0	88
	T+C+St	0.59	5.5	0.032	0.03	3.6	38.0	4.0	77
	M+C+St	0.70	5.7	0.038	0.019	3.6	44.0	4.0	82
	T+C+P	0.66	5.7	0.036	0.024	3.8	45.0	3.6	78
Soil Sampling date: 26/4/1998									
A	T+D	0.88	5.5	0.048	0.080	3.38	94	7	116
	T+C	0.57	5.5	0.031	0.110	2.99	83	5	107
	T+C+St	0.52	5.3	0.028	0.031	2.97	84	5	67
	M+C+St	1.03	5.5	0.056	0.070	3.40	70	5.4	118
	T+C+P	0.66	5.7	0.036	0.039	3.77	59	4.7	40
B	T+D	0.31	5.0	0.017	0.027	3.27	56	5.8	109
	T+C	0.52	5.5	0.028	0.019	3.45	90	4	106
	T+C+St	0.66	5.7	0.036	0.045	3.74	60	5.3	186
	M+C+St	0.39	6.0	0.021	0.039	3.45	77	4.6	118
	T+C+P	0.68	6.0	0.037	0.027	3.75	85	5	104
C	T+D	0.22	5.5	0.012	0.020	3.68	72	3.9	86

	T+C	0.28	5.5	0.015	0.015	3.59	61	4.6	78
	T+C+St	0.53	5.5	0.029	0.037	4.13	81	4.4	77
	M+C+St	0.70	6.0	0.038	0.030	3.39	55	4.7	78
	T+C+P	0.26	5.7	0.014	0.027	3.54	50	3.6	124
Soil Sampling date:15/10/1998									
A	T+D	1.07	5.5	0.058	0.064	3.39	65	4.5	69
	T+C	0.68	5.7	0.037	0.028	2.99	53	4.6	132
	T+C+St	1.03	5.5	0.056	0.009	3.66	60	4.6	70
	M+C+St	0.77	5.7	0.042	0.036	3.47	61	4.7	180
	T+C+P	0.85	5.0	0.046	0.047	3.49	50	4.7	100
B	T+D	1.18	5.7	0.064	0.016	3.91	37	4.1	59
	T+C	0.70	5.8	0.038	0.010	3.46	52	4.1	144
	T+C+St	1.05	5.3	0.057	0.003	3.59	52	4.7	156
	M+C+St	0.99	5.0	0.054	0.027	3.22	41	3.9	159
	T+C+P	1.18	5.5	0.064	0.021	3.67	41	4.7	138
C	T+D	0.70	5.0	0.038	0.021	3.71	36	3.9	71
	T+C	0.66	5.8	0.036	0.030	3.45	50	5.0	86
	M+C+St	0.77	5.7	0.042	0.042	3.98	49	4.3	89
	T+C+St	0.75	5.2	0.041	0.029	3.70	40	4.0	87
	T+C+P	0.57	5.3	0.031	0.013	4.38	30	4.0	97

Appendix 5.2 Soil Sample Analyses by X-Ray Fluorescence Spectrometry in The University of Wolverhampton

Soil Sampling date: 28/10/1997

Block	Treatment	Al_2O_3 (%)	CaO (%)	Fe_2O_3 (%)	K_2O (%)	MgO (%)	Na_2O (%)	P_2O_5 (%)	SiO_2 (%)	Cu (ppm)	Mn (ppm)	S (ppm)	Zn (ppm)
A	T+D	15.275	0.3815	8.1458	1.9758	0.6008	0.0126	0.1298	57.274	87.8	756.9	56.8	38.4
	T+C	15.798	0.3779	9.3556	1.6704	0.5821	0.0126	0.1149	57.290	76.8	1039.5	92.4	42.5
	T+C+St	17.152	0.3340	8.3479	1.8396	0.6258	0.0126	0.1196	57.060	58.4	812.9	43.1	31.2
	M+C+St	16.303	0.4524	9.3607	1.9582	0.6198	0.0126	0.1195	52.227	65.0	976.5	178.9	38.1
	T+C+P	15.767	0.3720	7.7296	2.0747	0.6735	0.0126	0.1307	60.622	58.1	910.3	109.9	39.8
B	T+D	17.056	0.3098	7.3952	1.8869	0.614	0.0126	0.1139	61.387	56.2	510.7	28.6	27.3
	T+C	17.134	0.6328	7.7812	2.4060	0.8671	0.0126	0.1124	55.713	51.0	669.7	13.0	28.2
	T+C+St	17.530	0.3847	8.0138	2.3795	0.6922	0.0126	0.1455	57.981	54.3	617.7	130.0	32.3
	M+C+St	16.712	0.3377	7.7821	2.1253	0.5797	0.0126	0.1232	57.818	55.3	599.0	152.1	28.8
	T+C+P	16.083	0.3104	7.8241	2.2842	0.5774	0.0126	0.1052	56.237	54.5	588.9	34.6	32.4
C	T+D	16.197	0.2574	6.2271	2.0452	0.5671	0.0126	0.0942	67.351	39.2	463.2	13.0	20.0
	T+C	16.392	0.3146	5.3131	2.0771	0.5725	0.0126	0.0113	71.213	33.5	426.1	84.9	18.4
	T+C+St	15.872	0.3439	6.3596	2.0910	0.5554	0.0126	0.1002	61.817	39.1	607.2	13.0	21.2
	M+C+St	17.095	0.3819	8.2099	2.2228	0.6392	0.0126	0.1102	57.760	54.1	740.0	13.0	26.8
	T+C+P	16.150	0.2888	5.5730	3.0024	0.5734	0.0126	0.0917	66.787	33.4	419.4	13.0	19.1

Appendix 5.3 Wang Jia Soil Analyses (before planting) of irrigated experiment in 1999

Soil Sampling Date: 27/4/99

Block	Treatment	Location	pH	SOM (%)	Total N (%)	Total P (%)	Total K (%)	Exch. N (ppm)	Exch. P (ppm)	Exc. K (ppm)
A	T+D	T	5.60	0.95	0.052	0.064	3.54	65.0	5.0	81
		M	5.60	1.04	0.057	0.058	3.52	67.0	5.5	94
		B	5.60	1.02	0.056	0.065	3.61	61.0	5.8	87
		mean	**5.60**	**1.00**	**0.055**	**0.062**	**3.56**	**64.3**	**5.4**	**87**
	T+C	T	5.60	1.00	0.055	0.051	3.47	75.0	5.1	168
		M	5.70	1.04	0.057	0.045	3.65	73.0	5.3	179
		B	5.70	1.00	0.055	0.052	3.62	81.0	5.6	186
		mean	**5.67**	**1.01**	**0.056**	**0.049**	**3.58**	**76.3**	**5.3**	**178**
	T+C+St	T	5.60	1.06	0.058	0.052	3.59	72.0	5.4	101
		M	5.70	0.98	0.054	0.041	3.64	76.0	4.8	120
		B	5.80	1.13	0.062	0.045	3.81	81.0	5.1	134
		mean	**5.70**	**1.06**	**0.058**	**0.046**	**3.68**	**76.3**	**5.1**	**118**
	M+C+St	T	5.80	1.42	0.078	0.045	3.54	75.0	5.2	189
		M	5.70	1.37	0.075	0.043	3.56	73.0	5.3	176
		B	5.80	1.29	0.071	0.047	3.58	89.0	6.1	178
		mean	**5.77**	**1.36**	**0.075**	**0.045**	**3.56**	**79.0**	**5.5**	**181**
	T+C+P	T	5.80	1.11	0.061	0.054	3.65	75.0	5.8	123
		M	5.70	1.06	0.058	0.053	3.45	78.0	5.6	125
		B	5.80	1.22	0.067	0.055	3.62	82.0	5.8	142
		mean	**5.77**	**1.13**	**0.062**	**0.054**	**3.57**	**78.3**	**5.7**	**130**
B	T+D	T	5.7	1.00	0.055	0.023	3.82	58.0	5.2	87
		M	5.8	1.04	0.057	0.024	3.89	59.0	4.8	97
		B	5.7	1.02	0.056	0.026	3.67	52.0	5.1	89
		mean	**5.7**	**1.02**	**0.056**	**0.024**	**3.79**	**56.3**	**5.0**	**91**
	T+C	T	5.8	0.75	0.041	0.021	3.57	64.0	6.1	186
		M	5.8	0.82	0.045	0.031	3.65	68.0	5.8	156
		B	5.8	1.13	0.062	0.028	3.74	75.0	6.4	174
		mean	**5.8**	**0.90**	**0.049**	**0.027**	**3.65**	**69.0**	**6.1**	**172**
	T+C+St	T	5.5	1.13	0.062	0.032	3.65	69.0	5.8	162
		M	5.3	1.16	0.064	0.027	3.78	67.0	6.0	142
		B	5.5	1.29	0.071	0.034	3.69	71.0	5.8	164

		mean	**5.4**	**1.20**	**0.066**	**0.031**	**3.71**	**69.0**	**5.9**	**156**
	M+C+St	T	5.7	1.31	0.072	0.028	3.46	58.0	6.2	167
		M	5.8	1.37	0.075	0.031	3.62	53.0	5.8	169
		B	5.8	1.24	0.068	0.027	3.85	64.0	5.9	180
		mean	**5.8**	**1.30**	**0.072**	**0.029**	**3.64**	**58.3**	**6.0**	**172**
	T+C+P	T	5.6	1.47	0.081	0.025	3.86	63.0	6.2	142
		M	5.8	1.31	0.072	0.026	3.75	75.0	6.0	146
		B	5.7	1.24	0.068	0.027	3.74	67.0	5.8	168
		mean	**5.7**	**1.34**	**0.074**	**0.026**	**3.78**	**68.3**	**6.0**	**152**
C	T+D	T	5.2	0.82	0.045	0.026	3.84	48.0	5.1	87
		M	5.4	0.78	0.043	0.024	3.96	56.0	5.6	86
		B	5.4	0.87	0.048	0.028	3.78	54.0	5.4	98
		mean	**5.3**	**0.83**	**0.045**	**0.026**	**3.86**	**52.7**	**5.37**	**90**
	T+C	T	5.7	0.75	0.041	0.035	3.56	67.0	5.5	110
		M	5.8	0.95	0.052	0.034	3.65	62.0	5.7	106
		B	5.8	1.00	0.055	0.042	3.84	74.0	5.8	124
		mean	**5.8**	**0.90**	**0.049**	**0.037**	**3.68**	**67.7**	**5.7**	**113**
	T+C+St	T	5.3	0.96	0.053	0.041	3.76	65.0	5.6	128
		M	5.4	0.98	0.054	0.037	3.86	63.0	5.9	134
		B	5.5	1.06	0.058	0.038	4.12	72.0	6.2	148
		mean	**5.4**	**1.00**	**0.055**	**0.039**	**3.91**	**66.7**	**5.9**	**137**
	M+C+St	T	5.8	0.86	0.047	0.047	4.21	68.0	5.8	164
		M	5.7	0.87	0.048	0.048	4.52	63.0	6.1	162
		B	5.8	1.02	0.056	0.052	4.68	75.0	6.2	182
		mean	**5.8**	**0.92**	**0.050**	**0.049**	**4.47**	**68.7**	**6.0**	**169**
	T+C+P	T	5.4	0.98	0.054	0.043	4.68	67.0	5.8	123
		M	5.3	1.16	0.064	0.042	4.87	84.0	6.2	124
		B	5.4	1.04	0.057	0.045	4.85	78.0	5.4	154
		mean	**5.4**	**1.06**	**0.058**	**0.043**	**4.80**	**76.3**	**5.80**	**134**

Appendix 5.4 Wang Jia Soil Sample Analyses Results of Non-irrigated Experiment in 1999										
Elements		**SOM**	**pH**	**Total N**	**Total P**	**Total K**	**Mean N**	**Mean P**	**Mean K**
Block	Treatment	(%)		(%)	(%)	(%)	(ppm)	(ppm)	(ppm)
A	T+D	1.20	5.8	0.065	0.035	3.4	62	6	87
	T+C	1.25	5.8	0.068	0.028	3.8	58	4	67
	T+C+St	1.18	5.5	0.064	0.016	3.7	54	3.5	96
	M+C+St	1.23	5.5	0.067	0.027	3.5	67	5	86
	T+C+P	1.34	5.6	0.073	0.034	3.8	72	4.5	82
B	T+D	1.14	5.6	0.062	0.037	3.2	56	4.3	106
	T+C	1.07	5.5	0.058	0.027	3.4	55	4.2	102
	T+C+St	1.23	5.8	0.067	0.034	3.7	58	4	110
	M+C+St	1.32	5.6	0.072	0.031	3.6	54	3.8	99
	T+C+P	1.36	5.8	0.074	0.025	3.7	47	3.4	103
Block C	T+D	1.18	5.6	0.064	0.018	3.8	64	3.4	86
	T+C	1.14	5.5	0.062	0.024	3.5	57	3.1	65
	T+C+St	1.07	5.8	0.058	0.026	3.4	59	3.5	87
	M+C+St	1.05	5.6	0.057	0.018	3.8	64	4.5	104
	T+C+P	1.21	5.5	0.066	0.034	3.4	58	4.8	98
Soil Sampling Date: 12/10/1999									
A	T+D	0.83	5.5	0.045	0.032	3.5	52	5.0	64
	T+C	0.99	5.5	0.054	0.023	3.6	56	2.2	62
	T+C+St	1.14	5.8	0.062	0.011	3.8	48	3.1	84
	M+C+St	1.20	5.8	0.065	0.023	3.6	62	4.1	82
	T+C+P	1.32	5.8	0.072	0.032	3.8	66	3.7	80
B	T+D	0.96	5.5	0.052	0.021	3	46	3.8	75
	T+C	1.03	5.5	0.056	0.024	3.2	45	3.2	74
	T+C+St	1.18	5.8	0.064	0.03	3.4	52	3.6	86
	M+C+St	1.31	5.6	0.071	0.031	3	50	2.2	92

	T+C+P	1.32	5.6	0.072	0.022	3.6	40	2.8	98
C	T+D	1.07	5.6	0.058	0.017	3.1	62	3.2	74
	T+C	1.10	5.6	0.060	0.022	3.2	50	3.0	65
	T+C+St	0.77	5.6	0.042	0.025	2.8	42	2.5	82
	M+C+St	0.94	5.5	0.051	0.019	3.1	60	4.0	87
	T+C+P	1.16	5.5	0.063	0.032	3.0	46	4.2	96

Appendix 5.5 Wang Jia Soil Sample (after harvesting) Analyses Results of experiment in 1999										
Soil Sampling Date: 15/10/99										
Block	Treatment	Location	pH	SOM (%)	Total N (%)	Total P (%)	Total K (%)	Exch. N (ppm)	Exch. P (ppm)	Exch. K (ppm)
A	T+D	T	5.5	0.86	0.047	0.058	3.41	50	3.8	65
		M	5.5	1.02	0.056	0.042	3.21	57	4.1	67
		B	5.5	1.04	0.057	0.065	3.52	65	4.7	71
		mean	**5.5**	**0.971**	**0.053**	**0.055**	**3.38**	**57.3**	**4.2**	**67.7**
	T+C	T	5.6	0.82	0.045	0.038	3.47	68	4.6	176
		M	5.6	0.96	0.053	0.041	3.49	71	4.8	187
		B	5.7	1.00	0.055	0.042	3.51	79	4.9	195
		mean	**5.6**	**0.928**	**0.051**	**0.040**	**3.49**	**72.7**	**4.8**	**186**
	T+C+St	T	5.7	1.02	0.056	0.045	3.58	61	4.3	85
		M	5.7	1.04	0.057	0.038	3.68	67	4.8	88
		B	5.8	1.11	0.061	0.042	3.75	71	5.1	112
		mean	**5.7**	**1.056**	**0.058**	**0.042**	**3.67**	**66.3**	**4.7**	**95**
	M+C+St	T	5.8	1.24	0.068	0.037	3.47	66	4.5	176
		M	5.8	1.29	0.071	0.041	3.51	67	4.8	182
		B	5.7	1.49	0.082	0.042	3.57	81	5.1	184
		mean	**5.8**	**1.341**	**0.0737**	**0.040**	**3.52**	**71.3**	**4.8**	**181**
	T+C+P	T	5.7	1.07	0.059	0.048	3.51	56	4.8	71
		M	5.8	1.04	0.057	0.047	3.49	58	5.1	76
		B	5.7	1.06	0.058	0.048	3.54	57	5.6	82
		mean	**5.7**	**1.056**	**0.058**	**0.048**	**3.513**	**57.0**	**5.2**	**76.3**
B	T+D	T	5.6	0.76	0.042	0.016	3.81	41	3.6	58
		M	5.7	0.93	0.051	0.018	3.82	45	3.6	59
		B	5.6	0.95	0.052	0.021	3.97	53	4.1	64
		mean	**5.6**	**0.880**	**0.048**	**0.018**	**3.87**	**46.3**	**3.8**	**60**
	T+C	T	5.7	0.69	0.038	0.015	3.51	53	4.5	150
		M	5.8	0.75	0.041	0.021	3.53	58	4.8	164
		B	5.8	1.06	0.058	0.034	3.61	61	5.7	187
		mean	**5.8**	**0.83**	**0.046**	**0.023**	**3.55**	**57.3**	**5.0**	**167**
	T+C+St	T	5.4	1.06	0.058	0.024	3.52	52	4.8	146
		M	5.2	1.11	0.061	0.026	3.61	57	5.2	157
		B	5.6	1.13	0.062	0.031	3.67	61	6.3	167

		mean	**5.4**	**1.10**	**0.060**	**0.027**	**3.60**	**56.7**	**5.4**	**157**
	M+C+St	T	5.8	1.16	0.064	0.025	3.34	42	4.1	158
		M	5.8	1.24	0.068	0.026	3.35	44	4.3	167
		B	5.7	1.29	0.071	0.031	3.62	47	4.8	172
		mean	**5.8**	**1.23**	**0.068**	**0.027**	**3.44**	**44.3**	**4.4**	**166**
	T+C+P	T	5.5	1.06	0.058	0.021	3.64	42	4.8	137
		M	5.7	1.09	0.060	0.023	3.67	45	5.1	142
		B	5.8	1.11	0.061	0.025	3.74	61	5.7	157
		mean	**5.7**	**1.09**	**0.060**	**0.023**	**3.68**	**49.3**	**5.2**	**145**
C	T+D	T	5.0	0.69	0.038	0.021	3.71	35	3.6	68
		M	5.1	0.75	0.041	0.023	3.78	38	4.2	79
		B	5.2	0.84	0.046	0.025	3.81	41	4.8	81
		mean	**5.1**	**0.76**	**0.042**	**0.023**	**3.77**	**38.0**	**4.2**	**76**
	T+C	T	5.6	0.67	0.037	0.031	3.46	51	5.2	91
		M	5.8	0.75	0.041	0.034	3.51	56	5.6	101
		B	5.8	0.95	0.052	0.041	3.62	62	5.8	121
		mean	**5.7**	**0.79**	**0.043**	**0.035**	**3.53**	**56.3**	**5.5**	**104**
	T+C+St	T	5.3	0.78	0.043	0.035	3.75	56	4.5	101
		M	5.4	0.82	0.045	0.037	3.83	58	5.1	104
		B	5.5	0.95	0.052	0.039	4.12	61	5.8	123
		mean	**5.4**	**0.85**	**0.047**	**0.037**	**3.90**	**58.3**	**5.1**	**109**
	M+C+St	T	5.7	0.76	0.042	0.048	4.1	58	4.31	145
		M	5.8	0.82	0.045	0.049	4.52	62	4.56	164
		B	5.8	0.87	0.048	0.053	4.67	71	4.82	182
		mean	**5.8**	**0.82**	**0.045**	**0.050**	**4.43**	**63.7**	**4.6**	**164**
	T+C+P	T	5.3	0.69	0.038	0.037	4.6	45	4.2	110
		M	5.4	0.75	0.041	0.035	4.6	48	4.6	123
		B	5.5	0.86	0.047	0.047	4.8	52	5.3	142
		mean	**5.4**	**0.76**	**0.042**	**0.040**	**4.67**	**48.3**	**4.7**	**125**

Appendix 5.6 Wang Jia Mean Soil Particle Size Distribution (μm) during the Period 1997 to 1999

Block	Year	1997			1999		
	Treatment	Clay	Silt	Sand	Clay	Silt	Sand
A	T+D	20.89	52.72	26.39	21.48	52.53	25.99
	T+C	25.07	55.84	19.09	22.71	54.36	22.93
	T+C+St	22.38	53.62	24.00	24.35	52.60	23.05
	M+C+St	25.32	56.32	18.36	22.51	55.00	22.49
	T+C+P	22.39	54.19	23.42	22.20	54.93	22.87
B	T+D	20.31	54.37	25.32	21.47	53.37	25.16
	T+C	20.38	52.41	27.21	21.60	54.50	23.90
	T+C+St	20.33	55.86	23.81	22.69	51.12	26.19
	M+C+St	20.33	54.52	25.15	22.10	53.58	24.32
	T+C+P	19.45	53.51	27.04	22.74	52.95	24.31
C	T+D	20.61	52.39	27	21.08	51.24	27.68
	T+C	17.58	54.14	28.28	23.21	52.88	23.91
	T+C+St	18.7	50.86	30.44	22.7	51.27	26.03
	M+C+St	21.82	53.98	24.2	21.66	53.77	24.57
	T+C+P	18.83	51.24	29.93	22.08	53.04	24.88
Mean values							
Treatment		Clay	Silt	Sand	Clay	Silt	Sand
T+D		20.60	53.16	26.24	21.34	52.38	26.28
T+C		21.01	54.13	24.86	22.51	53.91	23.58
T+C+St		20.47	53.45	26.08	23.25	51.66	25.09
M+C+St		22.49	54.94	22.57	22.09	54.12	23.79
T+C+P		20.22	52.98	26.80	22.34	53.64	24.02

Appendix 5.7 Soil Sample (before planting in 1999) Analyses by X-Ray Fluorescence Spectrometry in The University of Wolverhampton Soil sampling: 28/04/1999														
Block	Treatment		Al_2O_3 (%)	CaO (%)	Fe_2O_3 (%)	K_2O (%)	MgO (%)	Na_2O (%)	P_2O_5 (%)	SiO_2 (%)	Cu (ppm)	Mn (ppm)	S (ppm)	Zn (ppm)
A	T+D	Top	21.9468	0.3538	8.3174	1.9848	0.9178	0.0126	0.1470	62.1497	58.9	728.7	317.6	35.8
		Middle	18.6547	0.3452	8.2145	1.7895	0.7365	0.0126	0.1435	62.8540	59.6	732.6	254.3	35.6
		Bottom	17.7517	0.3130	8.0841	1.8266	0.6885	0.0126	0.1244	64.0778	63.3	735.7	138.4	35.8
	T+C	Top	19.9285	0.3786	10.8142	1.8447	0.7525	0.0126	0.1279	51.9378	82.4	1247.0	314.0	48.3
		Middle	17.6892	0.3812	10.7213	1.7653	0.6345	0.0126	0.1324	52.6540	76.3	456.1	285.6	47.6
		Bottom	15.8884	0.3829	9.1444	1.7259	0.4942	0.0126	0.1460	53.2410	73.0	948.2	277.9	47.2
	T+C+St	Top	16.6816	0.3961	8.4403	1.9038	0.5262	0.0126	0.1374	53.0609	61.2	771.9	337.0	41.8
		Middle	18.2560	0.3546	7.6589	1.9425	0.6254	0.0126	0.1324	55.6341	58.3	654.2	258.1	36.5
		Bottom	19.4744	0.3456	7.4747	2.0765	0.7876	0.0126	0.1235	64.5530	52.5	545.2	195.9	29.0
	M+C+St	Top	19.9959	0.4423	8.5043	2.0684	0.8034	0.0126	0.1703	56.3072	59.4	824.7	329.7	34.0
		Middle	18.7541	0.4321	9.9123	1.9987	0.7689	0.0126	0.1542	54.3621	63.2	987.6	312.5	36.5
		Bottom	18.2147	0.4095	9.9560	1.9739	0.6728	0.0126	0.1330	53.2455	70.4	1099.0	300.4	41.8
	T+C+P	Top	17.0282	0.3594	8.1940	2.0698	0.6658	0.0126	0.1200	58.9335	57.7	845.5	305.6	44.2
		Middle	17.0211	0.3654	8.7563	2.0754	0.6542	0.0126	0.1256	56.2311	61.2	995.1	295.2	43.2
		Bottom	16.9674	0.3935	8.9508	2.1734	0.6425	0.0126	0.1383	53.5600	62.1	1090.4	290.1	42.5
B	T+D	Top	17.8663	0.3588	7.5045	1.8578	0.6336	0.0126	0.1213	63.1970	58.3	473.8	194.3	29.1
		Middle	17.5263	0.3254	7.2569	1.8654	0.6214	0.0126	0.1312	63.4510	56.2	487.5	153.6	26.5
		Bottom	17.3975	0.3091	7.0433	1.8418	0.6070	0.0126	0.1372	63.6125	50.9	500.6	128.0	25.6
	T+C	Top	18.5436	0.2877	7.7724	2.5262	0.8288	0.0126	0.1224	60.4137	52.7	547.5	111.5	31.8
		Middle	16.2543	0.3012	6.8791	2.3456	0.7456	0.0126	0.1228	65.4875	46.2	542.6	85.3	25.4
		Bottom	15.7679	0.3156	5.7493	2.0432	0.6077	0.0126	0.1231	69.2210	35.5	545.9	59.0	19.8
	T+C+St	Top	16.9591	0.3346	8.6605	2.2395	0.5881	0.0126	0.1314	55.6102	63.9	629.5	203.7	38.7
		Middle	17.0021	0.3457	8.1245	2.2687	0.6213	0.0126	0.1423	57.2640	58.6	623.1	210.4	36.4
		Bottom	17.0458	0.3740	7.7944	2.3351	0.6725	0.0126	0.1539	58.6778	54.6	612.4	215.8	35.3
	M+C+St	Top	16.9453	0.2467	6.3346	2.1387	0.7164	0.0126	0.0904	69.3241	44.8	405.6	130.0	20.6
		Middle	17.2583	0.2687	6.8879	2.0879	0.6914	0.0126	0.1254	65.3240	48.6	543.6	254.3	26.4
		Bottom	17.8157	0.3200	7.4922	2.0579	0.6444	0.0126	0.1329	60.5068	55.7	602.8	308.6	30.2
	T+C+P	Top	16.8812	0.3626	8.3807	2.2118	0.5829	0.0126	0.1421	55.5269	61.5	600.0	150.9	32.5
		Middle	16.8815	0.3526	0.7865	2.2356	0.6123	0.0126	0.1245	58.6912	55.3	621.3	85.6	25.9
		Bottom	16.8819	0.3303	7.3809	2.2855	0.6423	0.0126	0.115	62.3476	49.7	634.7	82.1	23.8
C	T+D	Top	15.7933	0.2812	6.7672	2.4769	0.7777	0.0126	0.1261	66.1995	49.1	503.0	136.8	22.2
		Middle	15.2341	0.3124	0.6897	2.5124	0.7125	0.0126	0.1285	62.4526	50.2	532.4	163.5	24.5
		Bottom	14.9048	0.3252	7.3237	2.5433	0.6423	0.0126	0.1361	59.7339	52.4	574.0	196.0	26.4
	T+C	Top	14.1495	0.2973	5.7085	2.2990	0.5918	0.0126	0.1493	69.9040	41.8	477.2	73.1	22.0
		Middle	13.5475	0.2864	5.5647	2.3560	0.5246	0.0126	0.1452	71.2650	25.6	421.3	157.3	21.8

		Bottom	13.1270	0.2601	5.2150	2.2402	0.4803	0.0126	0.1401	72.1220	33.8	395.8	205.9	21.4
	T+C+St	Top	17.0876	0.3008	8.1488	2.6862	0.8430	0.0126	0.1254	60.1753	56.9	588.7	198.8	33.4
		Middle	15.6580	0.3547	8.2456	2.5643	0.6480	0.0126	0.1235	55.6789	58.7	698.2	153.2	30.5
		Bottom	12.9096	0.4440	8.4632	2.4886	0.5376	0.0126	0.1228	50.8847	62.5	809.0	107.9	28.6
	M+C+St	Top	17.4881	0.3820	7.5125	2.2422	0.7445	0.0126	0.1267	63.2660	55.1	678.3	170.8	28.3
		Middle	17.1245	0.3721	7.5623	2.1456	0.7324	0.0126	0.1324	64.2500	53.2	698.2	213.1	31.2
		Bottom	16.8114	0.3781	7.5980	1.9178	0.7107	0.0126	0.1427	66.7433	52.6	722.3	250.9	35.9
	T+C+P	Top	16.4825	0.3474	6.6126	2.6807	0.8249	0.0126	0.1069	61.7997	44.6	542.7	88.4	20.1
		Middle	15.3600	0.3012	5.6831	2.5487	0.6940	0.0126	0.1207	65.8223	38.2	433.6	143.0	20.3
		Bottom	14.0456	0.3302	5.9407	2.4058	0.6033	0.0126	0.1001	65.6830	38.3	402.2	73.6	19.2

Appendix 5.8 Soil Sample (after harvesting in 1999) Analyses by X-Ray Fluorescence Spectrometry in The University of Wolverhampton														Soil sampling: 15/10/1999
Block	Treatment		Al_2O_3 (%)	CaO (%)	Fe_2O_3 (%)	K_2O (%)	MgO (%)	Na_2O (%)	P_2O_5 (%)	SiO_2 (%)	Cu (ppm)	Mn (ppm)	S (ppm)	Zn (ppm)
A	T+D	Top	16.3529	0.6325	7.6651	2.4593	0.9184	0.0126	0.0955	60.3077	52.1	627.7	94.0	31.2
		Middle	16.8759	0.5687	7.4568	2.1354	0.7584	0.0126	0.1123	62.3541	51.4	634.7	156.7	31.8
		Bottom	17.1370	0.3916	7.3559	1.8229	0.6239	0.0126	0.1486	63.0421	50.8	652.1	298.4	32.8
	T+C	Top	14.5431	0.3670	8.8776	1.6707	0.4507	0.0126	0.0997	54.4244	72.3	878.8	89.9	39.1
		Middle	15.0261	0.3946	8.8812	1.5876	0.4536	0.0126	0.1024	53.2461	68.7	924.4	114.5	40.3
		Bottom	15.5729	0.4051	8.8885	1.5334	0.4631	0.0126	0.1132	52.5115	64.9	974.6	127.4	41.0
	T+C+St	Top	16.2298	0.3364	8.2739	1.8177	0.5683	0.0126	0.0987	58.0572	62.8	813.7	165.0	32.1
		Middle	15.9634	0.3215	8.1245	1.7652	0.5124	0.0126	0.1012	59.8712	56.8	765.4	152.4	28.8
		Bottom	15.7755	0.3013	7.3736	1.6154	0.4656	0.0126	0.1083	61.9950	50.5	690.9	130.0	27.9
	M+C+St	Top	9.2954	0.4249	9.2190	1.7852	0.3750	0.0126	0.0832	38.8620	68.2	967.4	73.6	38.9
		Middle	13.2546	0.4125	8.8867	1.7645	0.4187	0.0126	0.1025	45.3240	61.2	954.3	65.8	38.7
		Bottom	15.7501	0.3937	8.7720	1.7424	0.4894	0.0126	0.1134	54.4254	59.5	941.0	60.4	38.6
	T+C+P	Top	15.0652	0.3597	7.5941	2.0371	0.6106	0.0126	0.1141	59.6258	55.6	903.5	122.9	38.5
		Middle	16.1254	0.3457	7.6458	1.9987	0.6121	0.0126	0.1214	59.8950	52.6	927.5	89.3	37.5
		Bottom	16.8937	0.3379	7.8423	1.9145	0.6133	0.0126	0.1273	60.1261	50.8	938.4	79.9	36.8
B	T+D	Top	17.6096	0.3038	7.4577	1.9080	0.6659	0.0126	0.1116	62.5285	55.2	508.2	123.5	30.1
		Middle	17.4524	0.3085	7.1245	1.8657	0.6624	0.0126	0.1198	63.2541	51.2	205.6	98.6	26.7
		Bottom	17.1151	0.3134	6.9323	1.7864	0.5924	0.0126	0.1247	64.0889	47.6	48.2	89.8	23.5
	T+C	Top	15.2852	0.2862	5.6387	2.1332	0.6306	0.0126	0.0890	69.5457	35.7	419.6	51.6	18.9
		Middle	16.1240	1.4253	6.2547	2.2015	0.8369	0.0126	0.0913	61.2545	40.2	52.4	36.5	23.1
		Bottom	16.4113	1.6397	7.1701	2.2148	1.3852	0.0126	0.0968	59.4520	45.3	618.3	29.4	26.6
	T+C+St	Top	16.8666	0.3858	7.9204	2.2896	0.6818	0.0126	0.1392	57.5487	57.8	604.5	168.8	35.4
		Middle	17.1254	0.3847	0.7689	0.2759	0.7021	0.0126	0.1456	58.3641	55.3	64.3	169.2	34.6
		Bottom	17.8021	0.3840	7.5608	2.2646	0.7117	0.0126	0.1506	59.8546	52.3	601.1	170.9	31.1
	M+C+St	Top	16.8165	0.3508	7.9091	2.1473	0.6474	0.0126	0.1206	59.4667	58.9	604.8	265.6	33.0
		Middle	17.1245	0.3425	7.6541	2.1024	0.6487	0.0126	0.1186	60.5472	59.6	578.9	315.3	28.7
		Bottom	17.7804	0.3008	7.3140	2.0176	0.6588	0.0126	0.111	61.0573	50.6	568.4	365.0	25.9
	T+C+P	Top	14.2225	0.3128	7.9290	2.2184	0.4403	0.0126	0.1005	55.2178	56.6	601.5	69.9	36.0
		Middle	15.2546	0.3145	7.8945	2.2164	0.5123	0.0126	0.1102	54.2654	55.3	589.7	78.4	31.8
		Bottom	16.9683	0.3262	7.6812	2.2107	0.5921	0.0126	0.1112	53.6476	52.6	568.1	94.0	28.5
C	T+D	Top	15.5930	0.3104	6.2193	2.1163	0.5738	0.0126	0.086	70.1576	43.8	465.8	156.5	21.4
		Middle	15.3687	0.2875	6.1245	2.0124	0.5124	0.0126	0.0914	69.8750	42.1	451.8	140.8	21.3
		Bottom	15.2188	0.2505	5.8807	1.9072	0.4366	0.0126	0.0943	68.8142	37.5	441.7	130.0	21.0
	T+C	Top	15.4780	0.2904	5.3390	2.1847	0.6168	0.0126	0.1217	70.8122	31.4	425.5	110.8	18.4

		Middle	15.1245	0.2785	5.1245	2.0152	0.5874	0.0126	0.1124	75.4863	29.8	412.3	124.5	17.6
		Bottom	14.8879	0.2677	4.8324	1.9362	0.4880	0.0126	0.1047	79.6041	28.2	387.8	130.0	16.6
	T+C+St	Top	16.7258	0.3401	6.1776	2.2087	0.6897	0.0126	0.1022	66.5094	38.5	577.4	130.0	23.5
		Middle	16.7256	0.3354	6.1712	2.1457	0.6458	0.0126	0.1022	67.8924	36.5	578.0	130.0	21.5
		Bottom	16.7249	0.3302	6.1687	2.0486	0.6305	0.0126	0.1022	69.1677	35.2	578.1	130.0	19.1
	M+C+St	Top	13.3515	0.3940	8.2797	2.1054	0.3658	0.0126	0.0882	52.5739	58.5	727.8	42.2	30.0
		Middle	14.6584	0.3654	7.8645	2.0789	0.4587	0.0126	0.1024	58.7961	52.5	712.8	32.5	28.7
		Bottom	16.7693	0.3532	7.3392	2.0681	0.6625	0.0126	0.1116	61.1666	47.7	699.6	20.3	25.2
	T+C+P	Top	14.3206	0.3737	8.2002	1.8682	0.4073	0.0489	0.1163	54.7589	62.2	760.9	94.6	38.8
		Middle	15.6478	0.3215	0.7542	2.2145	0.5642	0.0254	0.1024	65.4875	51.2	524.6	124.3	25.4
		Bottom	16.9249	0.2896	5.5574	2.2269	0.6691	0.0126	0.091	70.4942	36.7	390.8	130.0	18.0